PRE-PHASE A TECHNICAL STUDY FOR USE OF SAT V, INT 21 & OTHER SAT V DERIVATIVES TO DETERMINE AN OPTIMUM FOURTH STAGE

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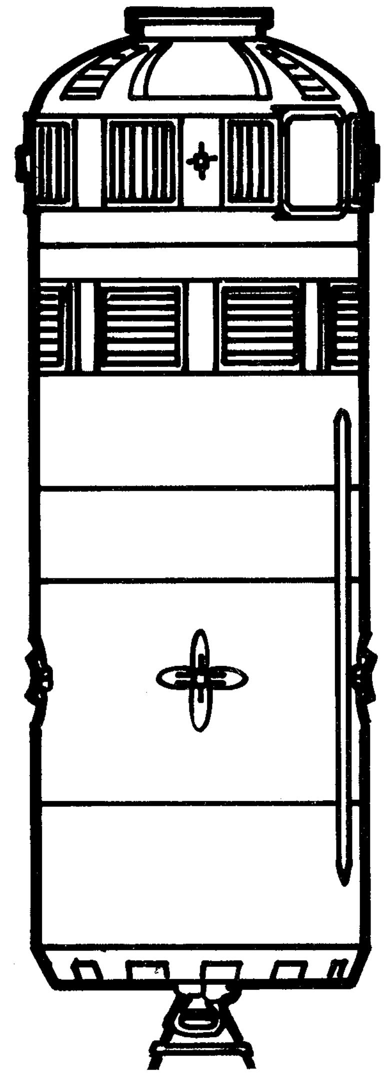

SPACE TUG

VOLUME I OF II
TECHNICAL VOLUME

BOOK 1 OF 4 –

INTRODUCTION
AND SUMMARY

FINAL REPORT

FEBRUARY 26, 1971

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PREPARED UNDER
CONTRACT NAS8–5608 SCHEDULE II

BY THE BOEING COMPANY
AEROSPACE GROUP
HUNTSVILLE, ALABAMA

CR103004

FINAL REPORT

TECHNICAL STUDY FOR THE USE OF THE SATURN V, INT-21 AND OTHER SATURN V DERIVATIVES TO DETERMINE AN OPTIMUM FOURTH STAGE

(SPACE TUG)

VOLUME I OF II
TECHNICAL VOLUME
BOOK I OF IV

PREPARED UNDER CONTRACT NAS8-5608

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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ABSTRACT

This technical volume is the first of two volumes presenting the final report documentation on "Technical Study of the Use of the Saturn V, INT-21 and other Saturn Derivatives to Determine an Optimum Fourth Stage, (Space Tug), Contract NAS8-5608, Schedule II, Part VII, Task X. Included in this volume are the Space Tug missions and mission modes, environments, design missions and requirements, vehicle selection, mission capability and operations, module and kit designs, resource implications and econometric analyses. Volume II of this report contains the results of detailed cost analyses.

The Space Tug is a major hardware element in the Integrated Space Program. It will interface with Earth-to-Orbit Shuttles, Space Stations, Nuclear Shuttles, Orbiting Propellant Stations, Satellites and other payloads. It must operate, both manned and unmanned, between and in earth and lunar orbit, between lunar orbit and the lunar surface, and on the lunar surface. It must perform unmanned interplanetary missions. This wide spectrum of missions, payloads and operations necessitates a modular concept where in various vehicle configurations can be assembled from an inventory of Space Tug modules and kits. The modules and kits identified include five modules (primary propulsion, secondary propulsion, astrionics, crew and cargo modules) and ten kits (payload adapter, manipulator arms, staging and separation adapters, clustering adapters, plug-in astrionics, environmental protection, RCS booster, landing legs, radar and auxiliary power).

This study contained seven tasks. The Task I activity defined the groundrules, guidelines and assumptions; the interface limitations imposed on the Tug by other space program elements; the missions and mission modes; the mission environments; mission requirements and Space Tug options for each family of missions.

The Task 2 trade studies developed mission event profiles; identified design requirements and criteria; conducted configuration and subsystem trades and identified desirable configurations and subsystems.

The Task 3 concept and subsystem selection activity assessed the desirable configuration and subsystems against the requirements to identify their relative merits. From these analyses, more detailed analyses were conducted on the more desirable modules, kits, systems and subsystems.

The Task 4 performance and mission environments determined flight trajectories and trajectory modes, and then identified the flight performance and flight environments. These were determined for the Saturn V/Tug missions as well as for the Earth-to-Orbit/Tug Missions.

ABSTRACT (Continued)

The Task 5 interface analyses identified and assessed the interfaces between (1) the Tug and other elements in the Integrated Space Program, (2) the Tug and its launch vehicles (Saturn V or Space Shuttle, (3) the Tug modules and kits.

The Task 6 final designs and resource requirements activities prepared the final subsystems, systems, modules and kits designs and weights. Inboard profiles of the major modules were prepared to illustrate arrangements and interfaces. Resource implications were identified including design, test, manufacturing, transportation, launch and costs. Schedules for each of the above areas were developed individually and then integrated into a master schedule.

The Task 7 activity included the conclusions, recommendations and preparation of this final report. Future studies and new technology requirements were identified. The study results provided data to identify Tug missions, mission modes, configuration requirements and options, designs, resources and costs.

KEY WORDS

Saturn V Fourth Stage
Space Tug
Earth-to-Orbit Shuttle
Low Earth Orbit Missions
Synchronous Missions
Lunar Orbit and Landing Missions
Interplanetary Missions
Integrated Space Program
Propulsion Module
Astrionics Module
Crew Module
Cargo Module
Space Tug Kits
EOS
OOS
Econometrics
Tug Costs

FOREWARD

This technical volume, Volume I, is one of two volumes presenting the results of a Pre-Phase A Technical Study for use of Sat V, INT-21 and other Sat V Derivatives to Determine an Optimum Fourth Stage (Space Tug). The cost volume (Volume II) presents the results of the cost analyses conducted. The size of the technical volume necessitates that it be divided into four books. These technical books are as follows:

Book I	Introduction and Summary		
Book II	Guidelines, Constraints, Missions, Environments, Requirements, Options and Trades		
Book III	Operational Econometrics, Conceptual Design and Resource Implications		
Book IV	Appendices	Appendix A	Lunar Surface Experience Requirements
		Appendix B	Parametric Performance Data

The Boeing Company performed this study at The Boeing/Huntsville facility for the NASA Marshall Space Flight Center, Huntsville, Alabama under the direction of the technical monitor Thomas W. Barrett, Advanced Systems Analysis Office, Vehicle Systems Group.

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SECTION I - INTRODUCTION AND SUMMARY

1.0 GENERAL

This report describes a feasibility analysis and technical evaluation of a reusable multi-mission upper stage system (Space Tug system) for the Saturn V vehicle family. The representative concepts defined are usable as fourth stages above the Saturn V vehicle, are adaptable to other Saturn V launch vehicle derivatives, and are compatible for launch with the Earth to Orbit Shuttle.

The Space Tug system is one of the major new systems anticipated to support an Integrated Space Program in the 1970-1980 time period. These potential systems include, in addition to the Space Tug, the Earth to Orbit Shuttle (EOS), Earth Orbiting Space Stations, Lunar Orbiting Space Stations, the Nuclear Shuttle and unmanned automated payloads. The Space Tug system is required to interface with these other space systems in the accomplishment of a multitude of missions envisioned for the future space program.

As an upper stage for the Saturn V type vehicles the fourth stage can (1) carry to and place in lunar orbit a Lunar Orbiting Space Station, and (2) carry payloads for interplanetary missions. The manned and unmanned missions the various elements of the Space Tug system can accomplish when operated separately from the launch vehicle include (1) transfer and assembly operations in low earth orbits, (2) transfer from low earth orbit to and operations within a geosynchronous orbit, (3) transfer between earth orbit and lunar orbit, (4) operations in lunar orbit, (5) transfer between lunar orbit and lunar surface, and (6) operations on the lunar surface.

When the nuclear shuttle is available, the Space Tug may be delivered from low earth orbit to lunar orbit or to geosynchronous orbit by the nuclear shuttle. The Space Tug elements will still, however, be delivered from earth to earth orbit with either the EOS or with the two stage Saturn V vehicle.

As indicated, the Space Tug must accomplish a wide variety of functions. It must operate in a manned or unmanned mode which requires that it have the capability of being controlled locally by man or remotely for unmanned applications. This spectrum of functional and mission requirements will require a variety of Space Tug components. To maximize the overall mission flexibility and minimize individual mission complexity modularized concepts were identified consisting of propulsion modules (both high energy and low energy) crew modules, cargo modules, astrionics modules and special purpose kits which can be assembled into different configurations to adapt to specific mission requirements.

The Space Tug will operate both in ground based and space based modes. In the ground based mode the Space Tug will be returned to the Earth's surface after the accomplishment of each mission. In the space based mode the Space

1.0 (Continued)

Tug will remain in space between missions. This latter mode requires that general refurbishment in space can be accomplished with ease of component exchange or repair. For major refurbishment the Space Tug could be returned to earth. By ground rule, the Space Tug systems must have an overall lifetime of ten years and must during this ten year lifetime be capable of performing at least ten major missions. The capability for self-checkout combined with operational simplicity must be provided. The Space Tug manned module must have air lock interface compatibility with all manned integrated program systems. Finally, the system must be designed and its operational modes defined such as to minimize overall program cost.

1.1 STUDY OBJECTIVE AND APPROACH

Considering the above requirements and application modes, this Pre-Phase A study was directed to satisfy the following objectives:

a. Identify all operational environmental requirements

b. Define subsystems and subsystem options which satisfy requirements for each mission.

c. Define alternative modular approaches for achieving system flexibility and commonality.

d. Select and define representative baseline configurations.

e. Identify key technical problems and concepts to be pursued during follow-on Phase A studies.

f. Determine the Space Tug system interaction as the prime interface in space with other space program elements.

To accomplish these objectives, this study identified the mission spectrum and the mission imposed requirements. The advantages and disadvantages of various modularized concepts, with their subsystems, to accomplish these missions were assessed. Based on these trade study assessments, baseline concepts were selected. Conceptual designs of these selected baseline systems were made. Resources, schedules and costs required for implementation and operation were identified. Conclusions and recommendations for future activity were defined based on the study analyses and results.

1.1 (Continued)

The Task and Milestone Schedule (Figure 1.1.0.0-1) illustrates the nine month study schedule, the major milestones and the flow of activity through the seven basic tasks from the establishment of the program guidelines to the identification of the final configuration.

The first three tasks were specifically oriented toward an overall systems study of the Space Tug missions and the options available for accomplishment of those missions. Sixty percent of the activity was directed towards these first three tasks. The remaining 40% of the activity was then directed toward conceptual designs of the baseline systems and the identification of the resources required for implementation and operation of these systems. The final task consisted of a comprehensive review of the study results and associated data and preparation of the final study documentation.

Figure 1.1.0.0-2, Study Phasing and Logic, shows the interrelationships of the study activities. Each of the major activities are keyed to the following sections of this report where applicable data and the results obtained from each of the major activities are discussed. In addition, unresolved problems are listed and recommendations for additional activity noted.

1.2 MISSIONS AND MISSION MODES

1.2.1 Mission Spectrum

The spectrum of Space Tug missions as depicted pictorially in Figures 1.2.1.0-1 and -2, was categorized as follows:

a. Earth orbit missions

1. Unmanned missions ground based
2. Unmanned missions space based
3. Manned missions ground based
4. Manned missions space based

b. Lunar landing missions

1. Unmanned cargo delivery
2. Manned landing missions
3. Rescue missions

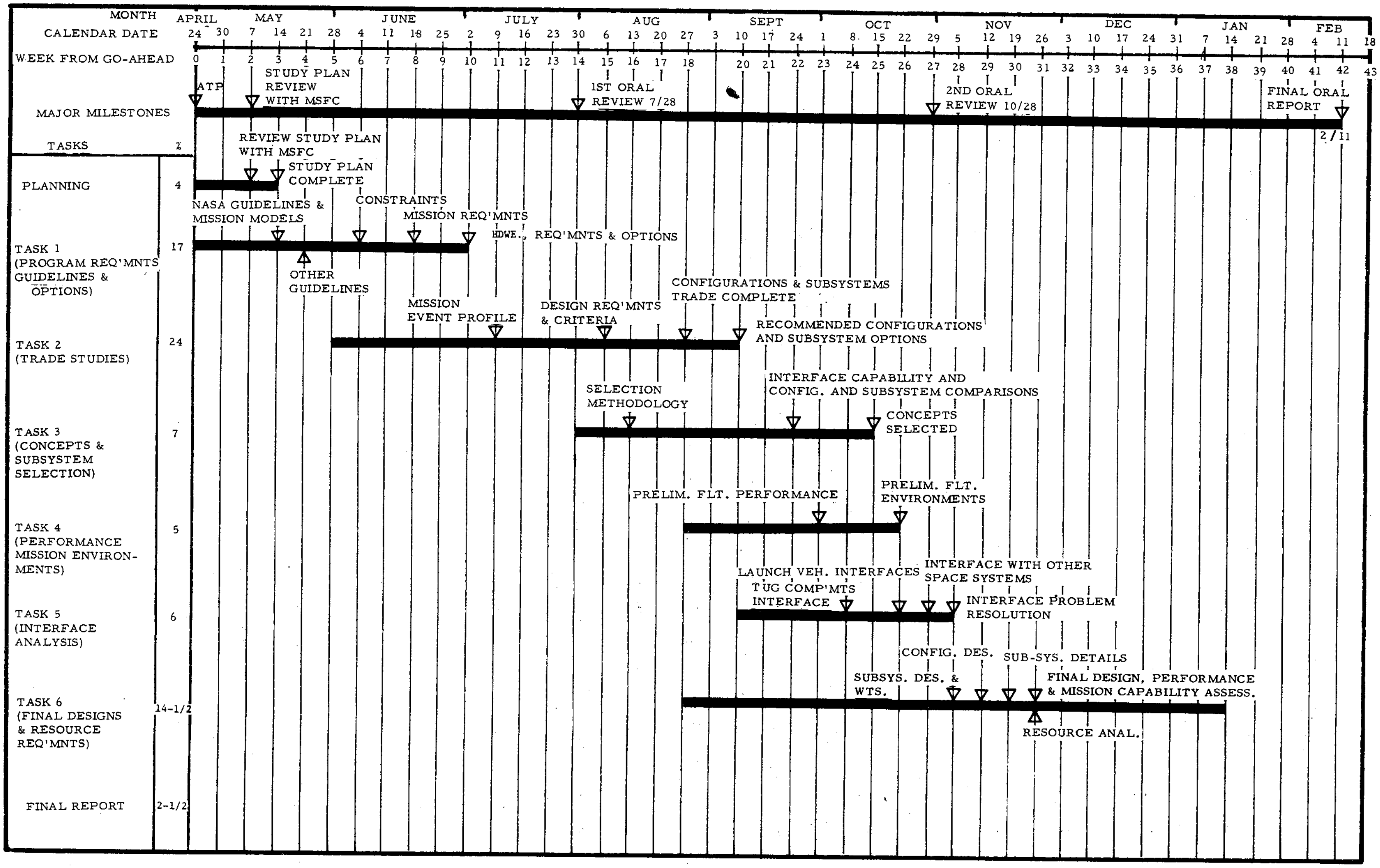
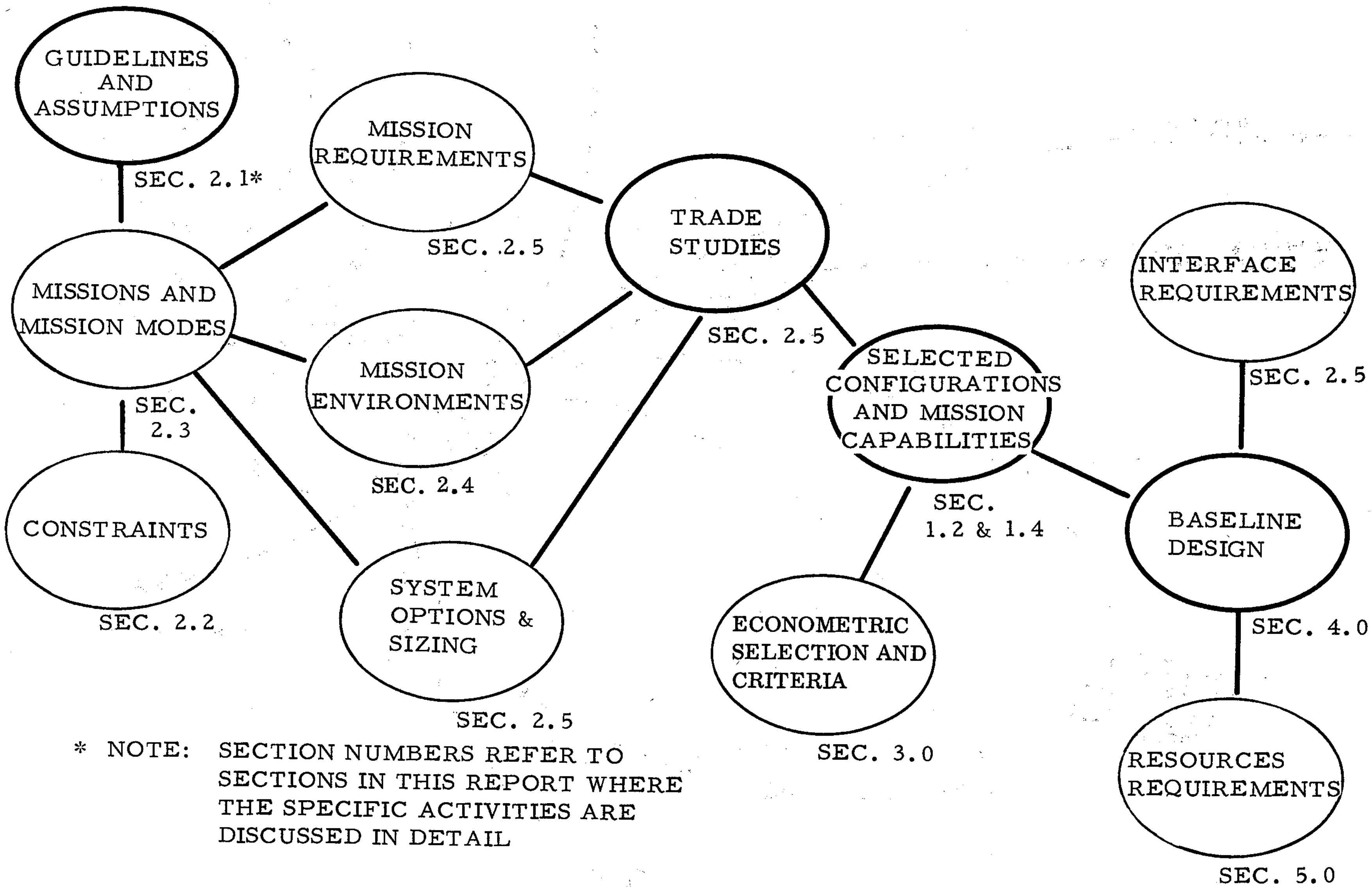


Figure 1.1.0.0-1. STUDY TASKS AND MILESTONE SCHEDULE



* NOTE: SECTION NUMBERS REFER TO SECTIONS IN THIS REPORT WHERE THE SPECIFIC ACTIVITIES ARE DISCUSSED IN DETAIL

Figure 1.1.0.0-2. STUDY LOGIC AND PHASING

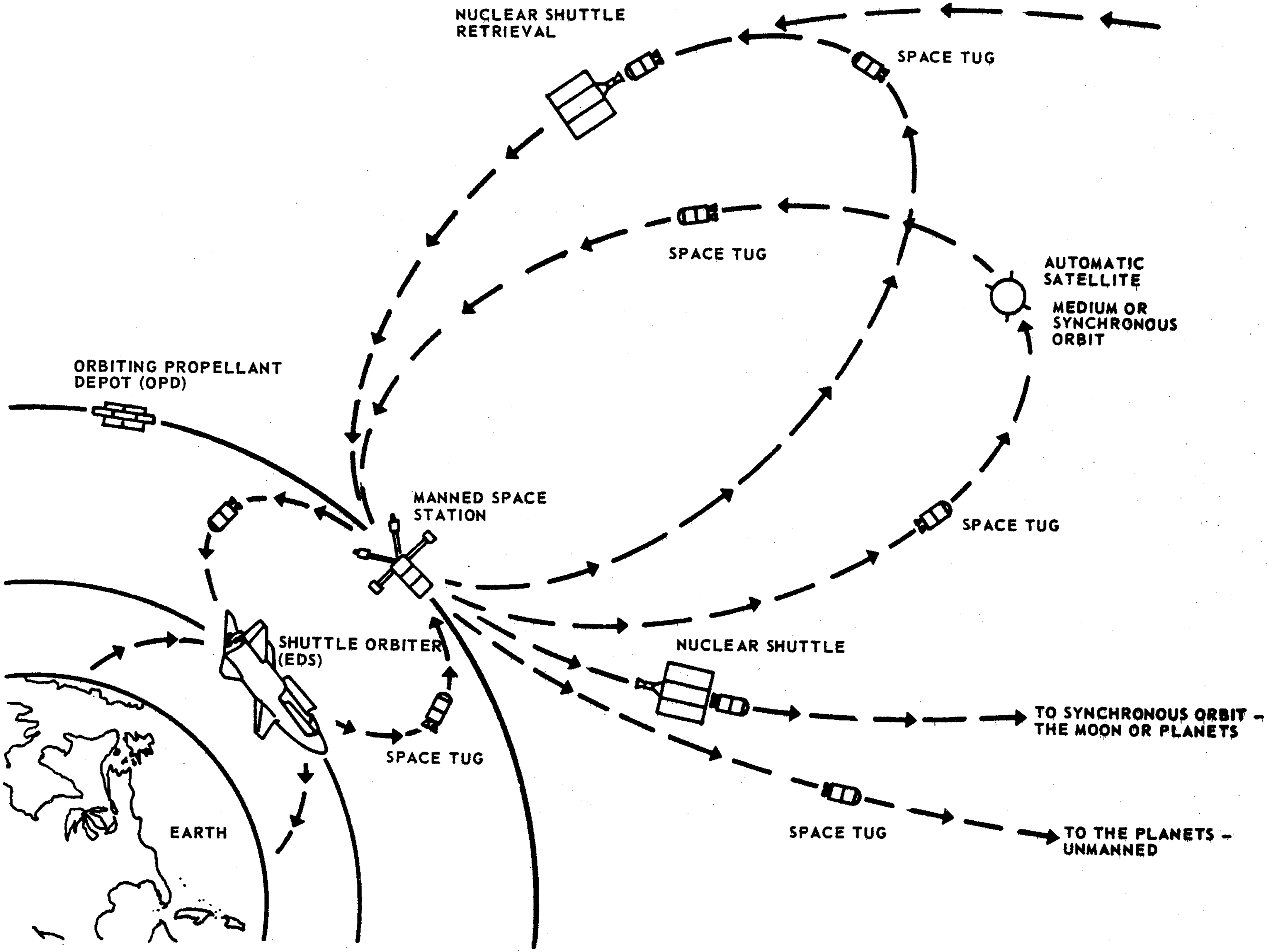


Figure 1.2.1.0-1. EARTH ORBIT BASED MISSIONS

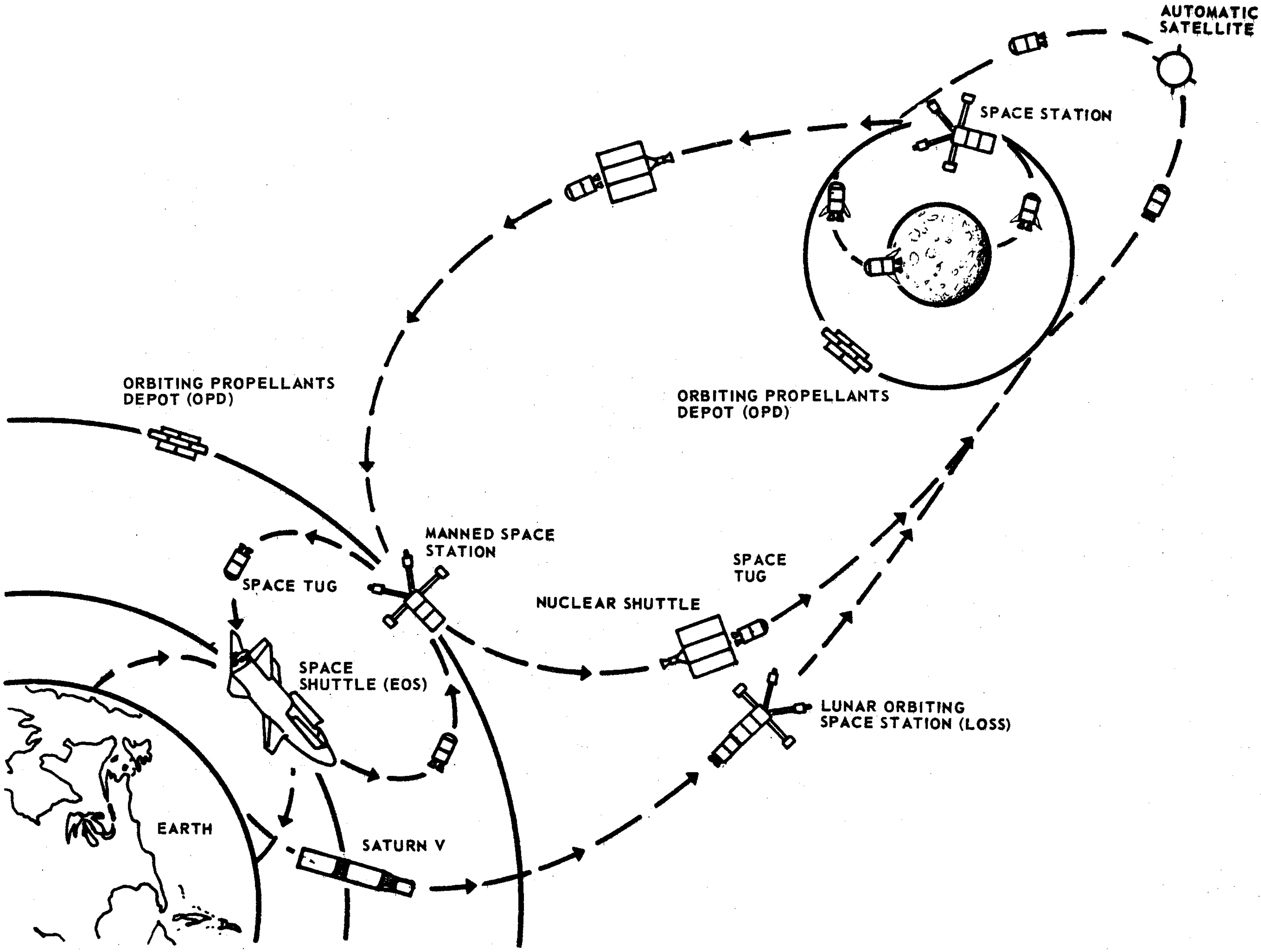


Figure 1.2.1.0-2. LUNAR MISSIONS

1.2.1 (Continued)

c. Translunar missions

    1. As an upper stage for the Saturn V
    2. As a chemical translunar shuttle

d. Inteplanetary missions

    1. Saturn V upper stage
    2. As injection stages from earth orbit

1.2.2 Significant Mission Modes

Two basic operational modes were considered for utilization of the Space Tug systems in conjunction with the Earth-to-Orbit Shuttle, i.e.:

a. Operations in a ground-based mode. For this mode the Tug and other mission components are launched from earth and are returned to earth by the EOS after mission accomplishment for preparation of the next mission. Several alternatives are available for accomplishing this mode:

    1. A single EOS launches the entire mission configuration to orbit. The Tug is deployed to complete the mission. After mission completion, the entire mission configuration is returned to earth in a single EOS (either the same EOS which launched the mission configuration and is waiting in orbit, or another which is separately launched to retrieve the mission configuration).

    2. The mission configuration is launched in more than one EOS with subsequent assembly in orbit. After mission accomplishment, the mission configuration would return to low earth orbit, be disassembled, and returned in a single or multiple EOS vehicle(s).

    3. A mode wherein an unfueled or partially fueled mission configuration is launched in a single EOS and fueled by an additional launch or multiple launches of EOS vehicles. After mission accomplishment the empty Tug and other mission components would be returned to earth in a single (or multiple) EOS vehicle(s).

b. Operations in a space-based mode. For this mode the Tug would be based in orbit and the other mission components delivered by the EOS. The EOS would also be required to transport fuel directly to the on-orbit Tug or to an orbiting propellant depot for subsequent transfer to the Tug. After accomplishment of the mission the Tug would return to and remain on

1.2.2 (Continued)

orbit. The EOS would be used to return retrieved payloads or other mission components to earth.

In the process of selecting the representative Space Tug elements, ground based and space based operational modes for both manned and unmanned mission were evaluated considering the weight and dimensional constraints imposed by the EOS, i.e., a 15 foot diameter by 60 foot long cargo bay and a range of payload capabilities to a 100 n.m. 28^{o} inclination circular earth orbit between 54,000 and 96,000 pounds. Detailed Space Tug configuration weight assessments were made to establish realistic Space Tug mass fractions relative to configuration size and mission requirements.

Modes which could reduce the energy requirements for high energy missions were also evaluated. One of the more significant modes identified was the "aerobraking return mode" as discussed in Paragraph 1.2.2.3.

1.2.2.1 Ground Based Implications

For accomplishment of the near term unmanned missions, the more desirable operational mode for the Space Tug and the EOS will be the ground based mode (1.2.2.a.1). This mode will require a smaller inventory of space transportation system (STS) components and fewer supporting facilities. It will provide better mission versatility, less design operational complexity, less investment and development cost, and improved safety and reliability. For accomplishment of DOD missions, this operational mode will be desirable not only for the above reasons but for the additional advantages of reduced vulnerability and faster response time.

Emphasis during the study was placed upon the accomplishment of the geosynchronous earth orbit missions, considering a ground based mode wherein the total mission configuration could be launched and returned in a single EOS. Payload placement, payload retrieval and round trip payload missions were evaluated. Alternative Space Tug configurations evaluated included expendable systems, reusable single and tandem stage systems, and systems consisting of combinations of reusable and expendable components including drop tanks.

Resulting data for payload placement and payload retrieval missions between a 100 n.m. 28^{o} inclined earth orbit and an equatorial geosynchronous earth orbit are shown in Figures 1.2.2.1-1 and -2. These figures plot the required size of the various configurations, based upon size dependent mass fractions, for varying payload sizes. For references, 54,000 and 80,000 pound shuttle payload constraints are crossplotted. Further, the 60 foot length constraint is shown for each configuration.

1.2.2.1 (Continued)

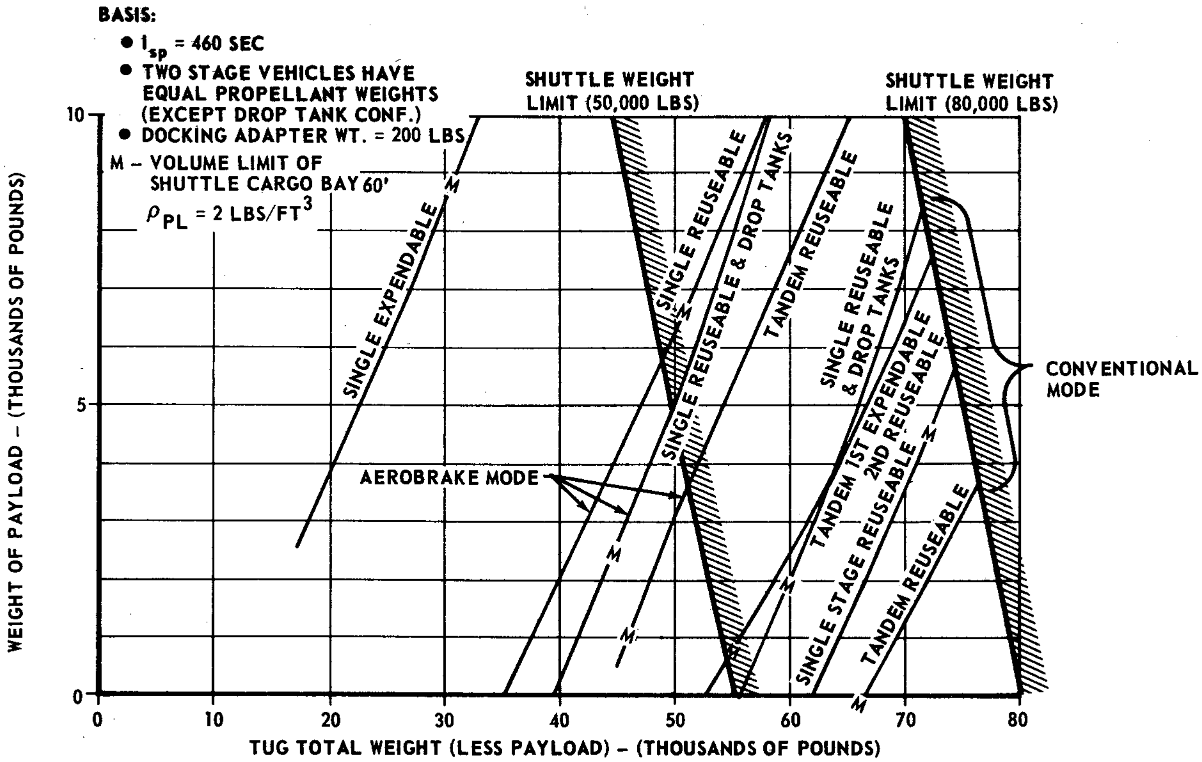


Figure 1.2.2.1-1. GEOSYNCHRONOUS PAYLOAD PLACEMENT COMPARISON

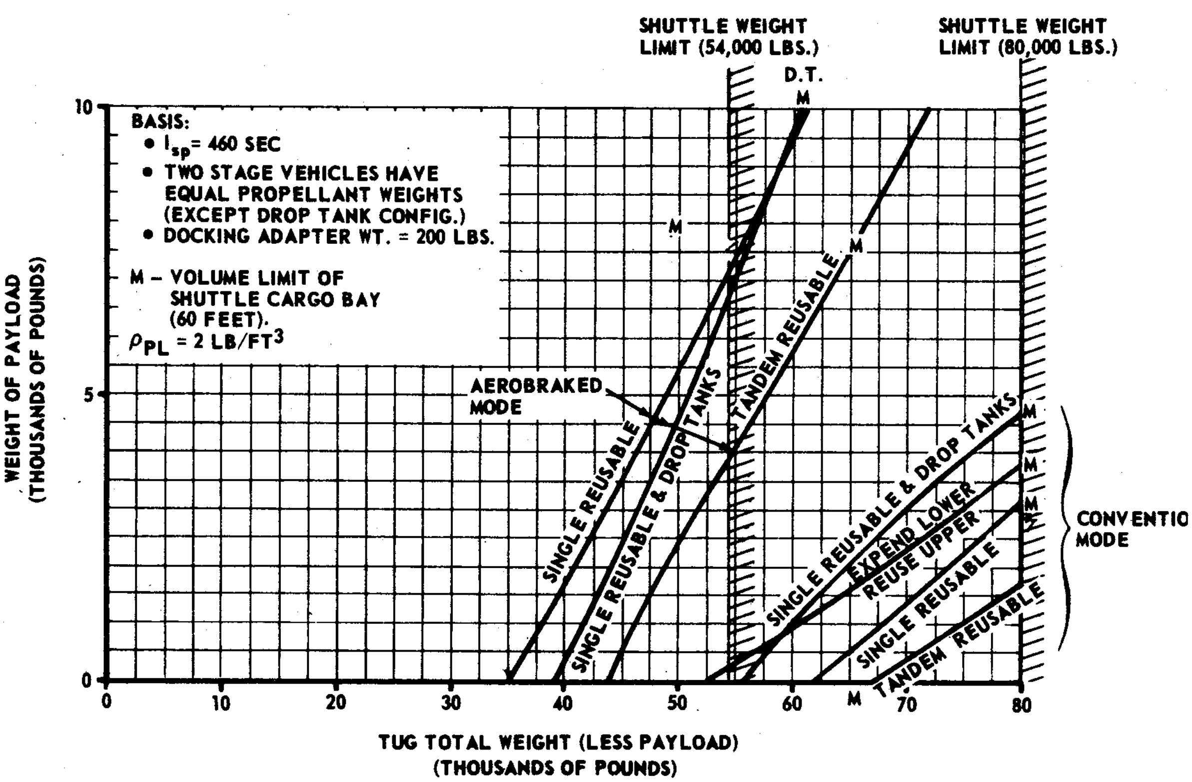


Figure 1.2.2.1-2. GEOSYNCHRONOUS PAYLOAD RETRIEVAL COMPARISON

1.2.2.1 **(Continued)**

These figures show that a single stage reusable system, operating in a "conventional" mode cannot, with a single launch of a 54,000 pound capability EOS perform any of the synchronous missions. For example, a single reuseable stage size of approximately 62,000 pounds is required to go and return from the geosynchronous orbit with a zero payload. Larger stages will, therefore be required for useful missions. If, however, a large single reuseable stage is utilized for such missions, (1) it must be space based or (2) it must be carried up empty or partially fueled, left in orbit and fueled by additional EOS launches prior to mission origination.

Figure 1.2.2.1-3 indicates the performance of this system will be extremely sensitive to variations in the performance parameters, i.e., specific impulse, mission delta velocity, and stage mass fraction. This figure considers a 77,000 pound single reuseable stage which has the capability of delivering 10,000 pounds to the geosynchronous earth orbit. This figure shows, however, that if the mass fraction is reduced from the nominal .881 value to a value of .878, which is equivalent to a 3% change in inert weight, a stage weighing 91,000 pounds will be required for placement of the 10,000 pounds. Similarly, this figure shows that if the Isp is reduced from 460 seconds to 444 seconds a stage weighing 92,000 pounds will be required. Further, if additional delta velocity is required for accomplishment of the mission (i.e., for rendezvous and docking, corrective maneuvers, and minor phase angle changes, etc.) the required stage size will increase. For example, an increase in the velocity requirements of 400 feet per second will increase the required stage size to approximately 90,000 pounds. Similar sensitivities were noted for a single reuseable stage for payload retrieval. These sensitivities directly relate to development risks. Production weight growth beyond design estmates is common. If such a weight growth were experienced, the vehicle could be too small for accomplishment of the design missions.

All of the other reuseable conventional vehicle alternatives will require more than one launch of the 54,000 pound EOS to place the complete mission components in orbit for accomplishment of any of the geosynchronous earth orbit missions. These other configuration alternatives, which consist of multi-stage systems, will have somewhat less sensitivities than those attributable to the single reusable stages. A single expendable stage can place large payloads in synchronous orbit but will not have the capability for retrieval or round trip missions.

For ground based missions requiring on-orbit assembly of fueled components, these operations may be conducted in the 100 n.m. low earth orbit, provided that no more than 5 days are required for this operation. Periods in excess

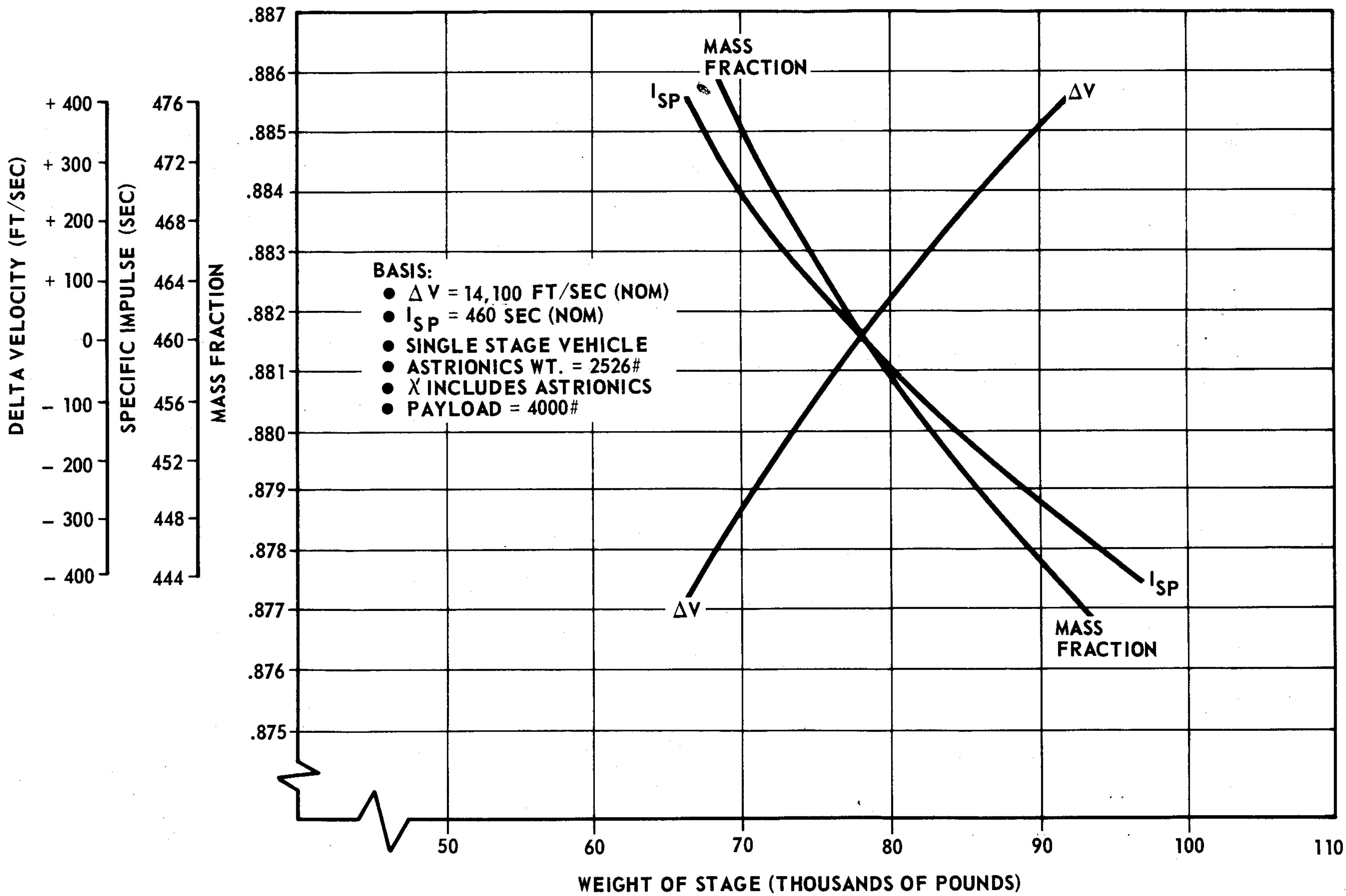


Figure 1.2.2.1-3. GEOSYNCHRONOUS PAYLOAD RETRIEVAL SENSITIVITY - SINGLE STAGE VEHCILE

1.2.2.1 (Continued)

of this time will require station keeping to maintain the components in orbit. Components which have returned from the mission and are empty will have shorter orbital decay times (i.e., on the order of less than a day in the 100 n.m. orbit) and, therefore, should be returned to a high orbit (270 n.m.) for subsequent retrieval by the shuttle.

On-orbit refueling operations of expended components can be accomplished in the lower orbit (which is desirable to maximize the payload delivery of the EOS) provided that these operations can be conducted in less than one day. Otherwise, station keeping will be required.

For the ground based reuseable systems to provide the best economy, it is necessary that the mission components be carried aloft and retrieved by the same shuttle launch.

1.2.2.2 Space Based Implications

As the space program matures and the spectrum of missions is enlarged to encompass increased manned operations in earth orbits and more extensive lunar exploration and exploitation missions, it will be desirable to use the space based operational mode (1.2.2.b). This mode will allow basing of a complete inventory of Tug components in earth orbit for assembly and fueling as required to support the space program on a mission to mission basis. With the space based mode, therefore, more cargo space and weight capability will be available in the EOS which will allow increased payload per EOS launch. An Orbiting Propellant Depot may be provided wherein the EOS can supply fuel for subsequent transfer to the Space Tug, Nuclear Shuttle, and other systems.

The Space based mode will allow for a fully loaded EOS for each mission. If the fuel carried to orbit by the EOS exceeds the immediate mission requirements, the excess capability can be carried to the Orbiting Propellant Depot (OPD). This mode will also allow for the excess EOS on-orbit maneuvering propellant to be utilized rather than dumped. This Orbiting Propellant Depot can also suffice as a refurbishment base for the space based Tug and other Space Transportation System elements. Similarly, manned Space Stations will be established in various low earth orbits and in lunar orbits which can provide for temporary storage of the Space Tug components and provide way stations for accomplishment of the various Space Tug missions.

For unmanned missions, however, a few potential advantages for space basing were identified, i.e.:

1.2.2.2 (Continued)

a. The slight possibility that fewer EOS launches will be required per mission. (for example the 7 day on-orbit capability of the EOS may require an additional launch to retrieve the ground-based tug). Similarly, the requirements for station keeping in the low earth orbit may require an additional launch to retrieve a ground based tug.

b. Space basing will allow the utilization of a larger, more efficient tug system (high mass fraction). If there is a preponderence of high energy missions this will be an advantage but it will be a detriment if there is a preponder-erence of low energy missions.

c. Space basing will allow more time for assembly of larger configurations and/or refueling operations in that these operations may be conducted in a high orbit. Such high orbit operations will, however, require a service tug to transport fuel and mission components from the shuttle at the 100 n.m. orbit to the base of operations in the high earth orbit (approximately 270 n.m.).

d. As for the manned missions, space basing will allow utilization of the excess ECS on-orbit maneuvering fuel and will allow a full EOS for every launch (i.e. any excess cargo capability of the EOS may be used to transport fuel or orbit).

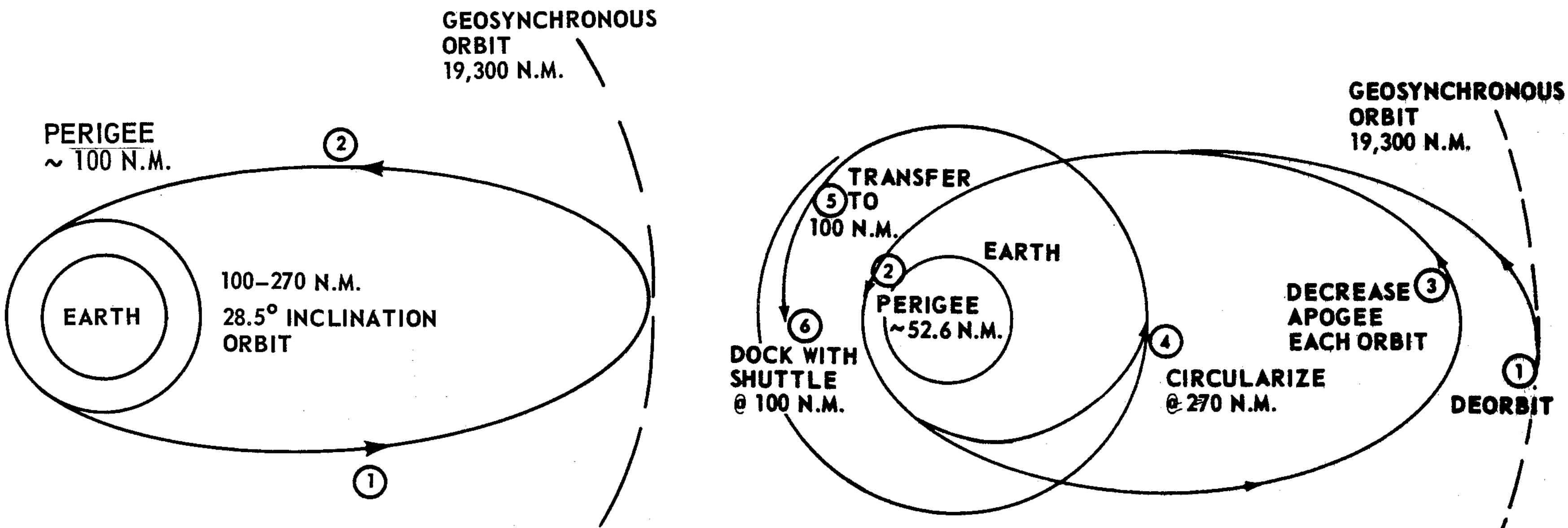
For space basing it will be desirable to have a space base and/or an orbiting propellant depot in each of the departure orbits. The majority of the unmanned missions will be flown from 28^{o} and 90^{o} inclination orbits. Operating from bases in other orbital planes will require excessive energy requirements for the Space Tug.

1.2.2.3 Aerobraking Return Mode

An attractive alternative mode to reduce sensitivity and to improve the payload capability of a single reuseable stage is the "Aerobraking Mode" for return from synchronous orbits. The previous Figure 1.2.2.1-1 shows that, by using this mode, a 48,000 pound stage (29,800 pound propellant capacity) can deliver 5500 pounds to orbit. Figure 1.2.2.1-2 shows that this system has a payload retrieval capability of 4800 pounds. For these capabilities, some improvements in stage length and payload packaging may be required to allow a fit within the EOS cargo bay constraints.

Figure 1.2.2.3-1 illustrates the "aerobraking return mode" and compares it to a "conventional mode" for geosynchronous missions. For aerobraking return, propulsive impulse is added initially at synchronous orbit to provide the necessary plane change and to establish a transfer orbit whose perigee is

CONVENTIONAL PROFILE   AEROBRAKING RETURN



Δ V BUDGET

1	ASCENT	14,500 FPS
2	DESCENT	14,500 FPS

PRELIMINARY TOTAL RETURN ΔV BUDGET:

1	DEORBIT	– 6240 FT/SEC
4	CIRCULARIZE	380
5	TRANSFER	656
6	DOCKING	400
	RESERVES	324
	TOTAL	8000 FT/SEC

AEROBRAKING TRAJECTORY DURING RETURN FROM GEOSYNCHRONOUS ORBIT

Figure 1.2.2.3-1. CONVENTIONAL VS. AEROBRAKING MISSION MODE

1.2.2.3 (Continued)

within the upper atmosphere. Flight through this upper atmosphere will provide braking such that the apogee will be lowered. Continued passes at a constant perigee will result in the desired apogee, where with a small circularization impulse, a low altitude phasing orbit can be established for subsequent rendezvous with the EOS. If sufficient time for braking is available, this maneuver can be accomplished with minimal heating and with little impact on Tug design and structures. Substantial improvements in avionics and sensor reliabilities will, however, be required for long return mission times. Because of the indicated potential of this aerobraking technique, aerobraking configurations should be investigated in depth in subsequent study activities.

1.3 SPACE TUG MODULES AND KITS

Space Tug Systems (Paragraph 1.0) must be compatible for both utilization as (1) upper stages and payload components for the Saturn V vehicle and its derivatives and (2) as upper stages and payload components for the Earth-to-Orbit Shuttle (EOS). Primary applications for the Space Tug/Saturn V Systems will be for:

a. Transportation of large payloads to lunar orbit.
b. Interplanetary missions.

The Space Tug systems may be utilized as payload components for the above missions when used in conjunction with the nuclear shuttle.

The majority of the Space Tug missions will, however, be in conjunction with the EOS. The baseline EOS considered for selection of the compatible Space Tug inventory was one with a 15 foot diameter by 60 foot long cargo bay. The maximum capability of this baseline EOS was specified as follows:

	28^{o} Inclination	55^{o} Inclination	90^{o} Inclination
100 n.m. circular earth orbit	54,000 lbs.	45,000 lbs.	26,500 lbs.
270 n.m. circular earth orbit	34,000 lbs.	25,000 lbs.	6,500 lbs.

Recent EOS design criteria, however, have established the EOS capability to the 100 n.m. 28-1/2^{o} inclination orbit at 65,000 pounds. This larger EOS

1.3 (Continued)

will allow utilization of a larger Tug propulsion module than that shown in the following inventory. This study has shown that the desirability of a larger propulsion module is generally questionable unless the size can be increased to on the order of 90,000 pounds. However, if the aerobraking mode is proven feasible, this larger EOS capability may allow either placement or retrieval of 10,000 pounds of payload to or from geosynchronous orbit with a single EOS launch. (Figures 1.2.2.1-1 and -2).

Considering the overall mission requirements and the required compatibility of the Space Tug with the other elements of the Space Transportation System, an inventory of Space Tug elements was selected. This inventory, as depicted in Figure 1.3.0.0-1, can accomplish, when assembled into the proper configurations, the overall mission spectrum.

The selected Tug inventory consists of the following components:

a. Primary propulsion modules with a 39,800 pound propellant capacity (designed for earth orbit missions).

b. Expendable drop tanks with 39,800 pound propellant capacity.

c. Secondary propulsion modules with a 16,800 pound propellant capacity (designed for earth orbit missions).

d. Astrionics modules (designed for earth orbit missions).

e. All purpose crew modules (outfitted as required for the various missions).

f. Cargo modules which use the shell of the all-purpose crew module.

g. Doughnut cargo modules (to carry experiments for the manned lunar landing missions).

h. Kits

   1. Payload retrieval and placement adapters

   2. A manipulator arm kit.

   3. Staging adapters and separation mechanisms.

   4. Clustering adapters (to provide for clustering of propulsion modules).

   5. Plug-in astrionics for specific mission requirements.

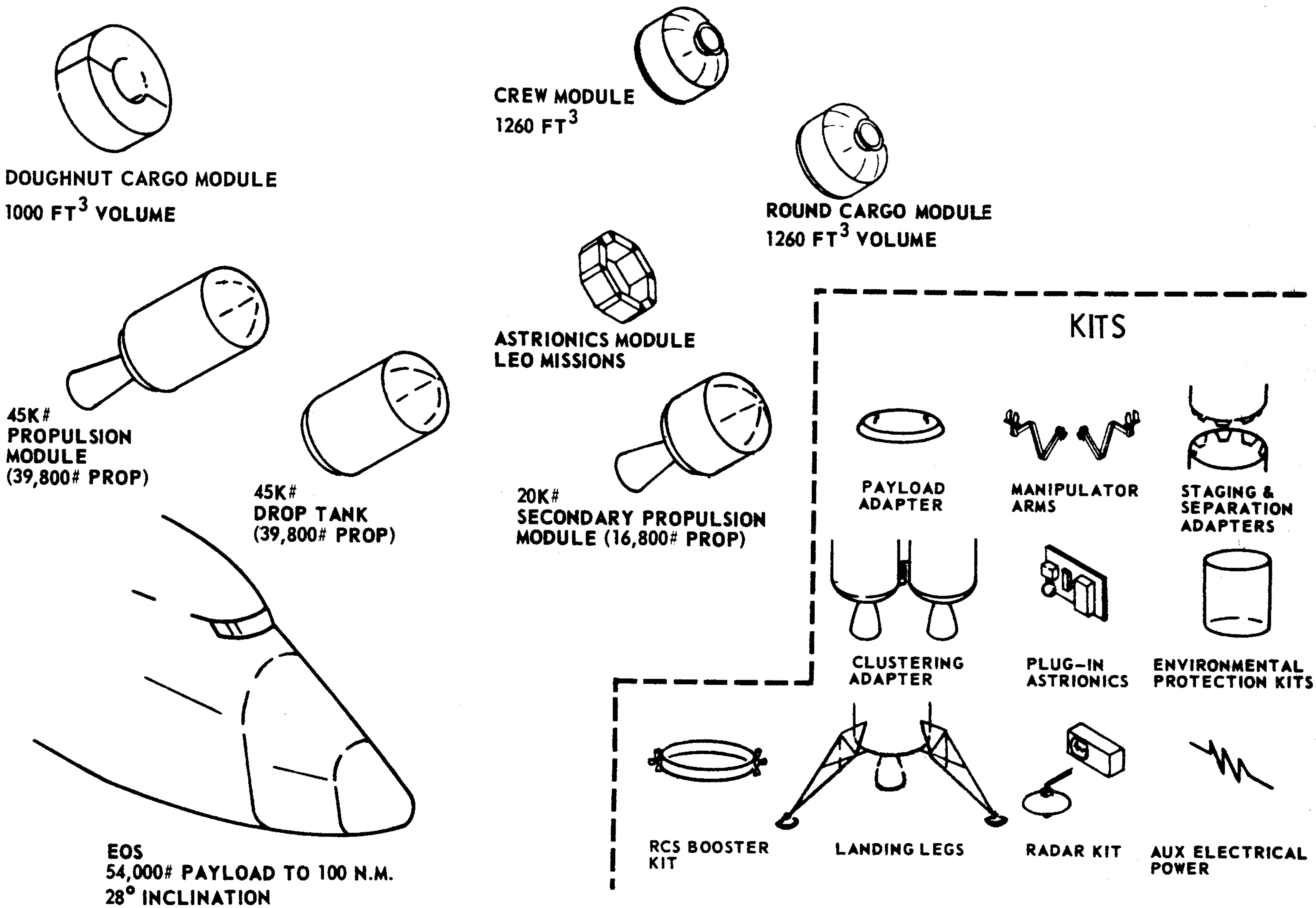


Figure 1.3.0.0-1. SPACE SHUTTLE/SPACE TUG ELEMENT INVENTORY

1.3 (Continued)

6. Insulation and micrometeoroid kits (for increasing the thermal and micrometeroid protection of the primary propulsion modules for the extended time of lunar landing missions).

7. Reaction Control System Booster Kit (to increase the reaction control system thrust for the lunar landing mode).

8. A landing leg kit (for lunar landing).

9. Radar kit for lunar landing.

10. Auxiliary power supply kit (for lunar surface operations.)

Details of the major tug elements in the selected inventory are portrayed in Figures 1.3.0.0-2 through -7.

Primary Propulsion Module

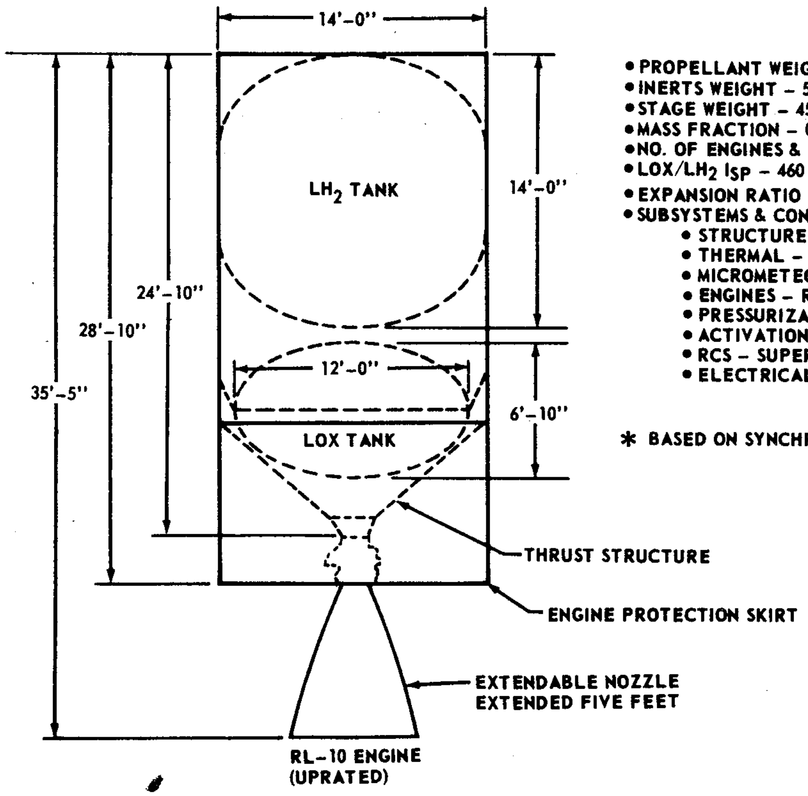
The primary propulsion module is designed for earth orbit and planetary missions. This module as shown in Figure 1.3.0.0-2 will use LOX/LH_2 propellant at a nominal mixture ratio, by weight, of 5 to 1, LOX to LH_2. The primary thrust will be provided by an uprated RL 10 engine which will provide a maximum thrust of 23,300 pounds at a specific impulse of 460 seconds. The engine is throttleable over a range of from 10 percent maximum thrust to maximum thrust. It is equipped with an extendible nozzle section which can be retracted 5 feet to minimize length for transport in the EOS or to minimize the interstage length when tandem stages are required or desired.

Utilization of this stage for lunar missions will require application of increased insulation and micrometeoroid shielding; a reaction control system booster kit; and auxiliary power kit; and a landing leg kit. These kits are discussed in subsequent paragraphs.

Drop Tanks

Expendable drop tanks for very high energy missions may be desirable to minimize the size of the required Space Tug configuration. The expendable drop tank, shown in Figure 1.3.0.0-3, consists of the same tankage arrangement and pressurization systems as that of the primary module. The insulation is the same as that provided to the primary propulsion module. The items deleted from the primary propulsion module to provide drop tanks include the reaction control system, engine, reaction control system, thrust structure, electrical actuation system for engine gimballing and some of the micrometorroid protection systems.

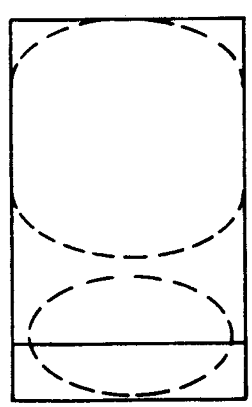
1.3 (Continued)



- PROPELLANT WEIGHT – 39,800 LBS
- INERTS WEIGHT – 5,610 LBS
- STAGE WEIGHT – 45,410 LBS
- MASS FRACTION – 0.876
- NO. OF ENGINES & THRUST – (1) ENGINE – 23,300#
- LOX/LH$_2$ I$_{SP}$ – 460 SEC
- EXPANSION RATIO – 225
- SUBSYSTEMS & CONSTRUCTION MATERIALS
  - STRUCTURES – 2219 T87 AL, 7075 T6 AL
  - THERMAL – SUPERINSULATION
  - MICROMETEOROID – HEXCEL FILLER, 2219 T87 SHIELD
  - ENGINES – RL-10-3-8 (UPRATED RL10)
  - PRESSURIZATION – GH$_e$ FOR LOX; GH$_2$ FOR LH$_2$
  - ACTIVATION – ELECTRICAL ACTUATORS
  - RCS – SUPERCRITICAL LOX/LH$_2$
  - ELECTRICAL – BATTERIES AND ELECTRICAL NETWORKS

* BASED ON SYNCHRONOUS MISSION

Figure 1.3.0.0-2. PRIMARY PROPULSION MODULE (45,000 # WEIGHT)



- PROPELLANT WEIGHT 39,800 LBS
- INERTS WEIGHT 4,090 LBS
- STAGE WEIGHT 43,890 LBS
- MASS FRACTION 0.906
- LOX/LH$_2$ I$_{SP}$ 460 SEC
- SUBSYSTEMS
  - STRUCTURES – 2219 T87 AL (TANKS) 7075 T6 (LOAD STRUCTURE)
  - THERMAL – SUPERINSULATION
  - MICROMETEOROID – HEXCEL FILLER, 2219 T87 SHIELD
  - PRESSURIZATION – GH$_e$ FOR LOX, GH$_2$ FOR LH$_2$
  - ELECTRICAL – BATTERIES AND ELECTRICAL NETWORK
  - DROP TANK FEED SYSTEM – 7075 T6 LINES

* BASED ON SYNCHRONOUS MISSIONS

Figure 1.3.0.0-3. DROP TANK MODULE

1.3 (Continued)

Secondary Propulsion Module

The secondary propulsion module, as shown in Figure 1 3 0.0-4, also was designed for application to low earth orbit missions only. It also will use LOX/ LH_2 fuel at a mixture ratio of 5 to 1. This stage will also employ the uprated RL-10 engine. For lower energy missions, however, the extendible nozzle section can be deleted.

Astrionics Module

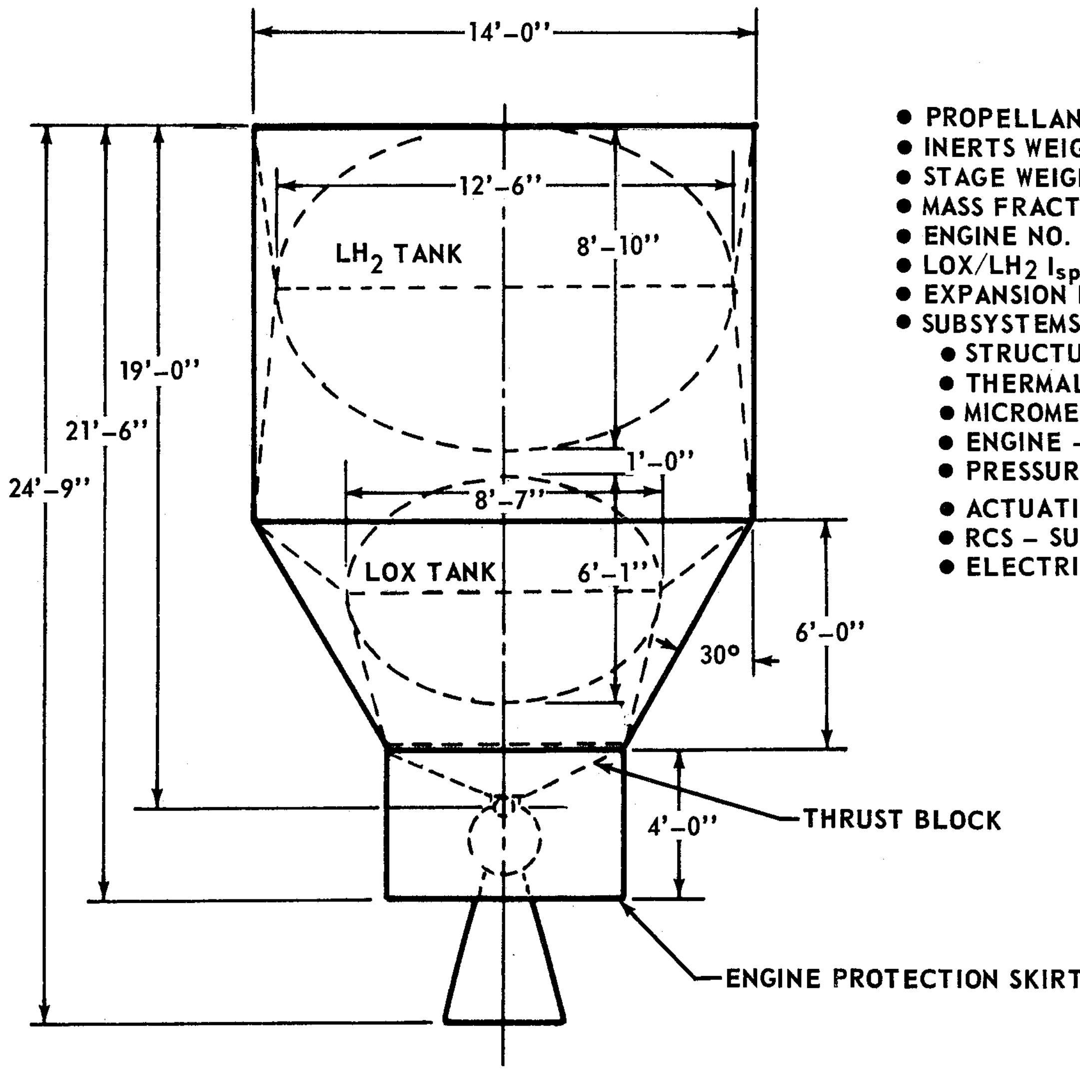
The basline astrionics module, as shown in Figure 1.3.0.0-5, was designed for accomplishment of the unmanned earth orbit missions in a reuseable tandem staged mode. Minor adaptions are required to adapt it to each of the two reuseable stages of the tandem stage vehicle. This baseline module can be stripped of unnecessary components for use in an expendable mode. Further, plug-in astrionics kits must be added for accomplishment of other specific reuseable missions. Weights for the baseline and its adaptations are shown in the Figure 1.3.0.0-5. The baseline astrionics module mission design, system descriptions and adaptations were provided by IBM in a parallel activity accomplished for NASA/MSFC. "Astrionics System Optimization and Modular Astrionics for NASA Missions after 1974", (MSFC-DRL-008 Line Item No. 268, IBM No. 69 K44 0006H).

Crew Module

The weights for the crew module are shown for the fifteen man, two-day low earth orbit mission and for the three man, fifty-day lunar landing mission. The crew module has a volume of 1,260 cubic feet and is pressurized to between 7 and 14 psia. Mounted atop the crew module is a docking adapter and on the side is an exit hatch which also can serve as an airlock. The manipulator arms are connected to the upper dome of the crew module. The crew module has three crew stations of which one is used for manipulator arm operation. A single man can operate the vehicle using one of the other two crew stations; however, to provide reliability, a second Space Tug operational crew station is provided.

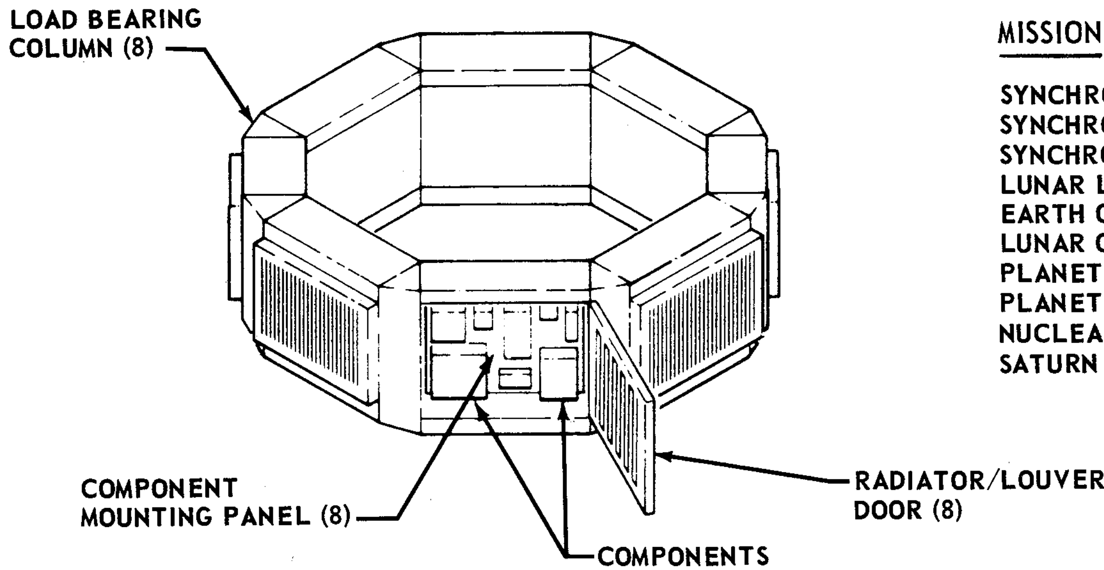
An aluminum bumper shield backed with hexcel filler for structural rigidity is provided for micrometeoroid protection. The hexcel is bonded in the one-inch space between the shield and the super insulation. In addition to the super insulation for thermal protection, a louver/radiator system is provided to maintain temperature control.

The crew module, as shown in Figure 1.4.0.0-6 is sized to accomplish either long duration missions with a small crew or short duration missions with 2 to 15 men.



- PROPELLANT WEIGHT – 16,800 LBS
- INERTS WEIGHT – 3,678 LBS
- STAGE WEIGHT – 20,415 LBS
- MASS FRACTION – 0.823
- ENGINE NO. & THRUST – (1) ENGINE – 23,300 LBS
- LOX/LH_2 I_{sp} – 460 SEC
- EXPANSION RATIO – 225
- SUBSYSTEMS & CONSTRUCTION MATERIALS
  - STRUCTURE – 2219 T87 AL, 7075 T6 AL
  - THERMAL – SUPERINSULATION
  - MICROMETEOROID – HEXCEL FILLER, 2219 T87 SHIELD
  - ENGINE – RL10A-3-8 (UPRATED RL 10)
  - PRESSURIZATION – GH_e FOR LOX, GH_2, FOR LH_2
  - ACTUATION – ELECTRICAL ACTUATORS
  - RCS – SUPERCRITICAL LOX/LH_2
  - ELECTRICAL – BATTERIES AND ELECTRICAL NETWORKS

Figure 1.3.0.0-4. SECONDARY PROPULSION MODULE (20,000 # WEIGHT)

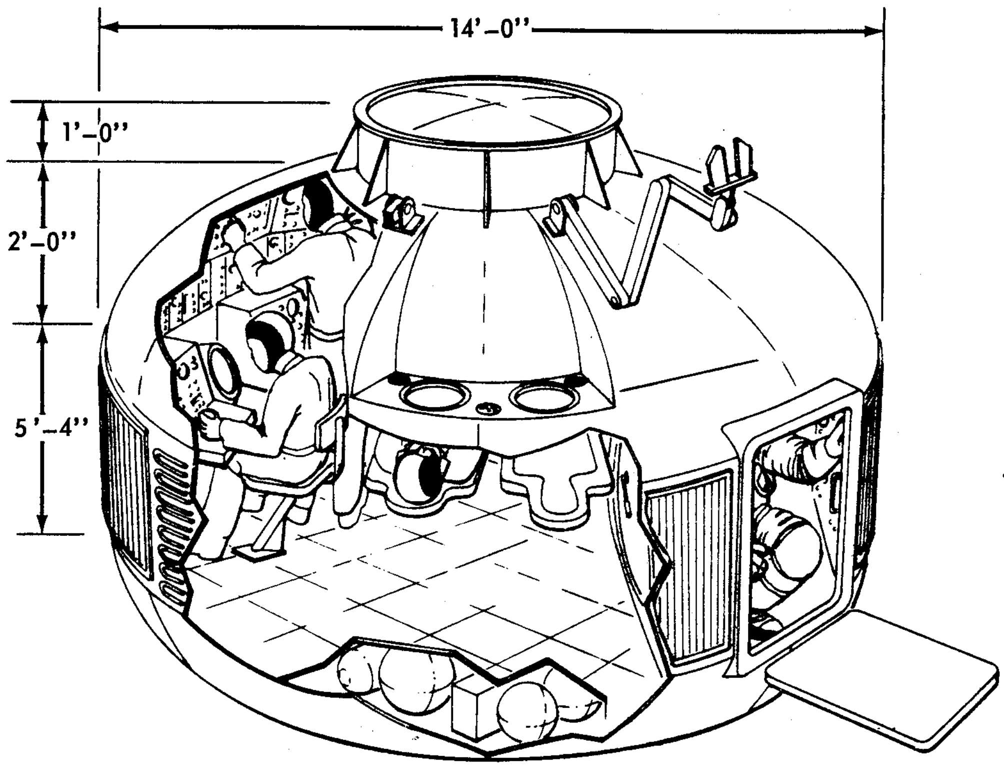


MISSION	WEIGHT (LBS)
SYNCHRONOUS (EXPENDABLE TUG)	1890
SYNCHRONOUS (REUSABLE 1ST STAGE)	2389
SYNCHRONOUS (REUSABLE 2ND STAGE)	2526
LUNAR LANDING	3115
EARTH ORBIT OPERATIONS	2723
LUNAR ORBIT OPERATIONS	2719
PLANETARY (REUSABLE 1ST STAGE)	2417
PLANETARY (EXPENDABLE 2ND STAGE)	2090
NUCLEAR SHUTTLE (REUSABLE)	3314
SATURN V – 4TH STAGE	2621

SYSTEM DESCRIPTION

- COMMAND AND CONTROL – USB AND VHF EQUIPMENT, TV, AUDIO, ANTENNA
- STRUCTURES – ALUMINUM HONEYCOMB SHELL OR OPEN FRAME
- THERMAL CONDITIONING – COOLANT PUMP, HEAT EXCHANGER ACCUMULATOR, FLUIDS, RADIATORS, LOUVERS, PANELS, INSULATION, PLUMBING
- ON BOARD T & C/O – CENTRAL COMPUTER OR BITE
- DATA MANAGEMENT – CPU, RANDOM ACCESS MAIN MEMORY, BUS CONTROL, IO, CAU, MAGNETIC STORAGE TAPE, DISPLAY, AUX. MONITOR COMPUTER
- NAVIGATION, GUIDANCE AND CONTROL – IMU, LASER RADAR, STAR TRACKERS (2), LANDMARK TRACKER, HORIZON SENSOR, LANDING RADAR
- ELECTRICAL POWER – 2 KW FUEL CELLS, BATTERY, DC REGULATOR, BATTERY CHARGER
- ELECTRICAL NETWORKS – SIU, DATA BUS, POWER DISTRIBUTOR, AUX. POWER DISTRIBUTOR, JUNCTION BOXES, WIRES & CABLES

Figure 1.3.0.0-5. ASTRIONIC MODULE



• WEIGHTS

	15 MAN 2 DAY	3 MAN 50 DAY
• STRUCTURE	2497	2497
• CREW SYSTEMS	3689	1705
• EC/LSS	1267	2602
• ELECTRICAL POWER	130	130
• COMMUNICATIONS	327	327
• INSTRUMENTATION	188	188
• CONTROL	60	60
• MISCELLANEOUS EQUIP.	80	80
• EXPENDABLES	295	1279
• CONTINGENCY	853	887
TOTAL	9386	9755

• VOLUME – 1260 CU FT

• ATMOSPHERE – 7–14.7 PSIA

• SYSTEMS DESCRIPTION

• STRUCTURE – 2219 T87 SHELL, 7075 T6 LOAD CARRYING STRUCTURE,
– 2219 T87 MICROMETEOROID SHIELD WITH HEXCEL FILLER
– SUPER INSULATION, RADIATORS, LOUVERS, PANELS, FLUIDS, PUMP HEAT EXCHANGER, ACCUMULATOR
– AIRLOCKS AND DOCKING PORTS

• CREW SYSTEMS – BUNKS, SEATS, FOOD, MEDICAL, CLOTHING, HYGIENE, CREW, EVA SUITS, PLSS

• MISC. SYSTEMS – MANIPULATOR ARMS DISPLAYS AND CONTROLS, MAINTENANCE EQUIPMENT, ETC.

• INCLUDES WEIGHT OF CREW

• SYSTEMS DESCRIPTIONS

• EC/LSS – CABIN PRESSURIZATION, O_2/N_2, WATER, WASTE MANAGEMENT, ETC.

• ELECTRICAL POWER – BATTERIES, REGULATORS, JUNCTION BOXES, WIRES, CABLES, POWER DISTRIBUTOR

• COMMUNICATION & DATA MANAGEMENT – TV, AUDIO, ANTENNA

• INSTRUMENTATION – DISPLAYS, CONTROLS, WIRING LIGHTING

• CONTROLS – RCS, EXPENDABLES, LINES, INST.

Figure 1.3.0.0-6. CREW MODULE

1.3 (Continued)

Cargo Modules

Two basic cargo modules, as shown in Figure 1.3.0.0-7, are envisioned for the accomplishment of the Space Tug missions. The round cargo module will be used for bulk cargo for both the low earth orbit and synchronous missions.

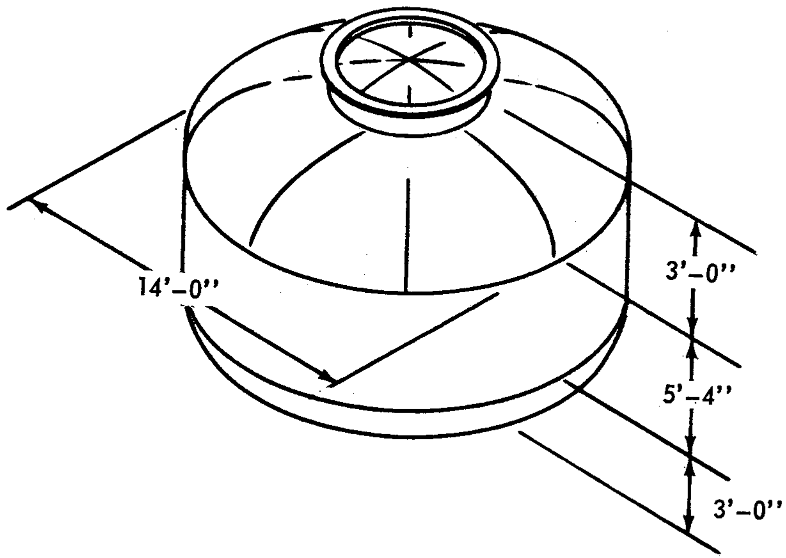
The doughnut shaped cargo module, which will mount around the nozzle of the propulsion module, is provided for easy access for lunar landing missions. Both of these cargo modules are special modules for carrying low payload weight cargos (under 10,000 pounds). For large or peculiarly shaped cargos i.e., space station modules, telescopes, etc., it was assumed that specific cargo modules or perhaps none at all would be utilized. In the latter case, the payload must be designed to withstand the environments imposed during launch and delivery to the desired orbit or landing site. It was assumed that all satellites would fall in this latter category.

The round cargo module (same shell as the crew module) has a payload weight carrying capacity of 20,000 pounds and a volume of 1260 cubic feet. A minimum of electrical, instrumentation and environmental control systems will be provided. Racks and other bracketry will be provided for stacking the small packages which are envisioned for the bulk cargo to the space station. Liquids can be housed in the lower ellipsoidal section of the cargo module.

The doughnut shaped cargo module for the lunar landing mission will be mounted beneath the propulsion module such that it will be approximately five feet above the lunar surface. (The engine will extend through the center opening.) Side hatches are provided for unloading at the lunar surface. This module is sized for an approximate 10,000 pound capability and has a volume of approximately 1,000 cubic feet. Because of the doughnut shape, the diameter must be increased to beyond the Space Shuttle cargo bay diameter of 15 feet to accommodate the Lunar Roving Vehicle and the larger experiment components. It, therefore, will require delivery from earth in the EOS in two sections which will be joined in orbit by two connecting latches 180° apart. The shape and increased diameter results in a larger weight (4500 pounds) than that of the round module.

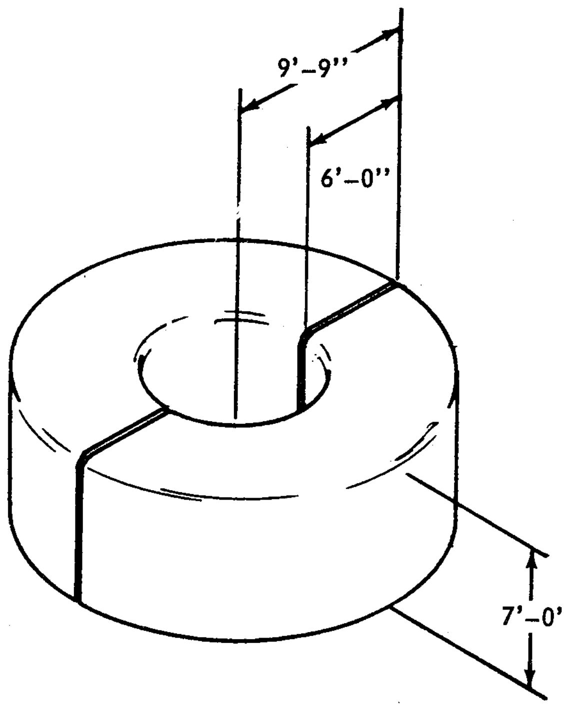
Kits

A Payload Placement and Retrieval Adapter will be provided to the astrionics/propulsion module configuration for accomplishment of an unmanned mission.



ROUND MODULE

- CAPACITY – 20,000 LBS PAYLOAD
- VOLUME – 1,260 CUBIC FEET
- WEIGHT – 2901 LBS
- NON-PRESSURIZED STRUCTURE
- STRUCTURAL MATERIAL – 2219 T87 & 7075 T6 AL.
- SYSTEMS/SUBSYSTEMS – ELECTRICAL, INSTRUMENTATION & ENVIRONMENTAL CONTROL SUBSYSTEMS
- ONE PIECE CONSTRUCTION WITH TWO EXITS



DOUGHNUT MODULE

- CAPACITY – 10,000 LBS PAYLOAD
- VOLUME – 1,000 CUBIC FEET
- WEIGHT – 4493 LBS
- NON-PRESSURIZED STRUCTURE
- STRUCTURAL MATERIAL – 2219 T87 & 7075 T6 AL
- SYSTEMS/SUBSYSTEMS – ELECTRICAL, INSTRUMENTATION & ENVIRONMENTAL CONTROL SYSTEMS
- TWO HALF DONUT CONSTRUCTION WITH TWO CONNECTING LATCHES 180° APART PLUS EXIT TO SURFACE

Figure 1.3.0.0-7. CARGO MODULE

1.3 (Continued)

This adapter, which may be unique for each payload will provide for attachment and subsequence separation of the payload for placement missions and will for the more complex retrieval missions provide the functions necessary to capture, fold and secure the payload for return to the EOS. Such adapters were not designed during this activity. Subsequent study activity should investigate requirements and develop conceptual designs for these devices.

A manipulator arm kit will be required for operations in space such as, (1) assembly, maintenance, etc., of space based components; (2) fuel transport operations; (3) change out of the nuclear stage reactors; (4) station keeping operations; and (5) other activities requiring remote extravehicular activities. Each of these requirements for the manipulator arms will impose unique requirements. No detail designs of manipulator arm systems were generated by this activity. The Matrix Research Company, however, is presently performing some studies in this area for NASA/MSFC. Some of their resulting technical and cost data were provided to Boeing for this activity.

(Note that in the weight of the crew module, a weight allowance for the manipulator arms control and display systems was made.) Subsequent study activities of the Space Tug and of other related space systems should define the requirements and design concepts for such devices.

For assembly of the Tug propulsion modules (and/or drop tanks) for the larger configurations, staging adapters and separation mechanisms will be required. Design concepts for these mechanisms were developed considering tandem stage (or stacked) configurations.

For manned operations, docking adapters will be required for docking of the Tug to the EOS, Space Stations, the Nuclear Shuttle, the Orbiting Propellant Depot, and other elements. As this docking adapter will be a major interface for manned systems, design concepts which provide compatibility with all of these systems must be developed. Desirable concepts should be defined for each of the above systems and an integrated study performed to define specific designs which are compatible with all systems.

Deployment mechanisms for deploying the Space Tug from the Saturn V, the Nuclear Shuttle and the EOS will depend upon the specific requirements to be defined for the mutual operation of these systems. Additional study activity is required to define these systems.

Some of the configurations defined will require connection in parallel of the Space Tug propulsion modules (and/or drop tanks). Clustering adapters for this application must be defined.

1.3 (Continued)

The basic astrionics module discussed above was designed for accomplishment of the unmanned synchronous earth orbit mission with a tandem staged reuseable configuration. Other missions will place separate specific requirements upon the astrionics module. To meet these requirements plug-in astrionics kits for each of the specific missions will be provided. Certain missions will be accomplished with expendable modules. For these applications expensive astrionics components will be removed and replaced with cheaper components. Similarly, redundant systems which may be deleted because of the reduced reliability requirements will be removed and replaced by supplementary circuitry.

Some of these adaptations were defined in a parallel study activity performed by IBM: "Astrionics System Optimization and Module Astrionics for NASA Missions After 1974" (MSFC-DRL-008 Line Item No. 268, IBM No.69-K44-0006H). Thorough analysis of the requirements of each of the specific missions will be required before the overall required inventory of astrionics plug-in kits can be designed.

Additional insulation and micrometeoroid protection must be provided to the primary propulsion modules to provide for the extended mission times of the lunar landing missions. Application of these kits for these purposes will increase the insulation and micrometeoroid protection weight of the primary propulsion module from 448 to 855 pounds.

For the lunar landing mode, additional reaction control thrust must be provided. An auxiliary reaction control system kit which doubles the available thrust in each of the pitch and yaw axes will be added to the primary propulsion module for these missions.

For landing on the lunar surface, a lunar landing leg kit must be provided. In addition to the basic landing legs, doublers to provide hard points for connection to the primary propulsion module will be required.

Four landing legs, 90^{o} apart, of tubular aluminum constructions will weigh approximately 1900 pounds. A shock absorber system consisting of liquid springs and landing discs will absorb the shock and provide a leveling mechanism for the Space Tug vehicle. The upper attachment point for the landing legs is approximately 15 feet off the ground at approximately the mid point of the LOX tank. The lower intersecting point is approximately even with the lower part of the LOX tank. The height of the vehicle makes it necessary to have the landing legs that extend a great distance from the center of the vehicle to provide stability (i.e. approximately 30 feet, from the center of the landing disc to the center of the vehicle). For the lunar landing mode the laser radar provided by the baseline astrionics module will

1.3 (Continued)

not be sufficient as dust and other debris kicked up during landing may attenuate the laser signal. An auxiliary RF continuous wave radar to overcome this difficulty will be provided.

Certain experiments on the lunar surface will require power beyond that available from the crew and astrionics modules. An auxiliary power supply kit will be carried as part of the cargo to the lunar surface to meet these increased power requirements. This auxiliary power supply kit will consist of a two KW fuel cell weighing 100 pounds plus 346 pounds of inerts (tanks, lines, valves, etc.) and 1700 pounds of reactants to give a total system weight of 2145 pounds.

1.4 SELECTED CONFIGURATIONS AND MISSION CAPABILITIES

Considering the inventory of Space Tug elements discussed in paragraph 1.3, desirable configurations were defined for accomplishment of the spectrum of missions. Selection of these configurations were primarily based on minimum operational costs for each of the missions and on (as applicable) maximum utilization of the Earth Orbit Shuttle (EOS) payload capability.

The maximum capability of the baseline EOS used for this analysis was specified as follows:

	28^o Inclination	55^o Inclination	90^o Inclination
100 n.m. circular earth orbit	54,000 lbs.	45,000 lbs.	26,500 lbs.
270 n.m. circular earth orbit	34,000 lbs.	25,000 lbs.	6,500 lbs.

It is recognized that the EOS capability is somewhat arbitrary at this time. Variations to the capability from that specified, could necessitate changing the sizes of the selected Space Tug elements and possibly require the use of different Space Tug vehicle configurations than those specified for accomplishment of the mission spectrum (data for these resizing analyses are presented in Paragraph 2.5 and in Appendix B).

The point designs presented will, however, provide a basis from which the overall Space Transportation System implications can be assessed. They are not intended to present the final recommended Space Tug system. It is intended that the analyses conducted to define these configurations and the specified capabilities coupled with the advantages and disadvantages as

1.4 (Continued)

stated will provide the necessary inputs for follow-on Space Transportation System activities. Such activities should investigate not only the Space Tug system but the interaction of all the Space Transportation System elements for accomplishment of an Integrated Space Program.

1.4.1 Earth Orbit Missions

1.4.1.1 Unmanned Earth Orbit Missions - Ground Based

The Space Tug elements considered for the various configurations for accomplishment of the unmanned earth orbit missions include the following:

a. Reuseable 39,800 pound propellant capacity primary propulsion modules configured for earth orbit missions (additional insulation and shielding are required for lunar missions).

b. Same modules as above but stripped for use in an expendable mode.

c. Reuseable 16,800 pound propellant capacity modules configured for same modules as discussed in (b) above but stripped for use in an expendable mode.

d. Expendable Astrionics module.

e. Reuseable Astrionics module configured for earth orbit missions (additional components are required for lunar missions.)

For these missions, no requirement for a cargo module was identified as each of the missions involves unique satellites. (It is assumed that each of these satellites has its own shroud and interface hardware.) The only other required Space Tug element for accomplishing these missions is a docking and/or retrieval adapter. Each configuration denoted had its payload capability penalized 200 pounds to account for this hardware.

The various configurations selected for accomplishment of the earth orbit missions are depicted in Figure 1.4.1.1-1. Figures 1.4.1.1-2 through -10 show the capability of these configurations relative to the following unmanned missions:

a. Missions originating from 28-1/2° inclined orbits:

   1. Payload placement (Figure 1.4.1.1-2)
   2. Payload retrieval (Figure 1.4.1.1-3)
   3. Payload round trip (Figure 1.4.1.1-4)

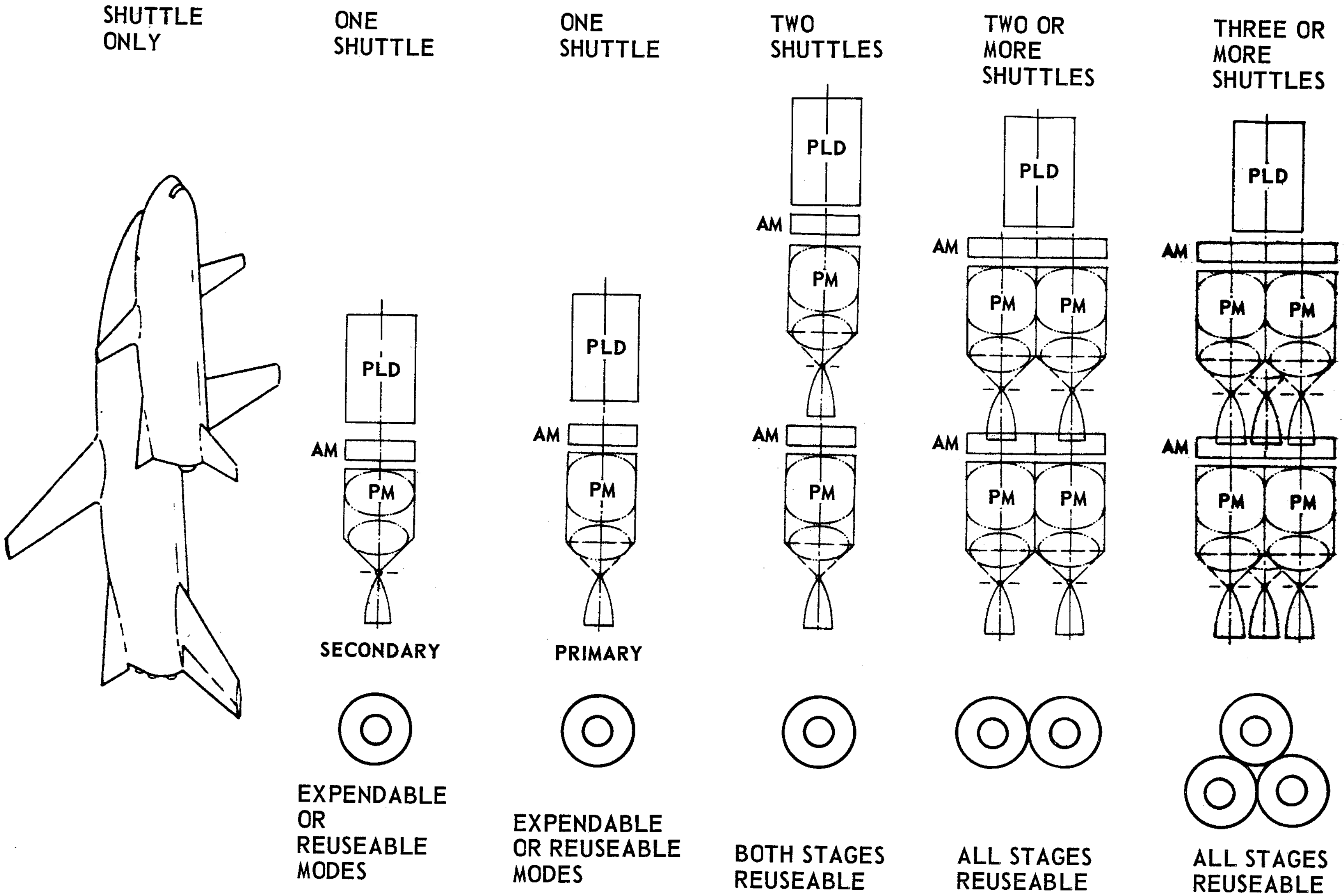


Figure 1.4.1.1-1. CONFIGURATIONS FOR UNMANNED EARTH ORBIT MISSIONS

1.4.1.1 (Continued)

b. Missions originating from 55^{o} inclined orbits:

1. Payload placement (Figure 1.4.1.1-5)
2. Payload retrieval (Figure 1.4.1.1-6)
3. Payload round trip (Figure 1.4.1.1-7)

c. Missions originating from polar orbits:

1. Payload placement (Figure 1.4.1.1-8)
2. Payload retrieval (Figure 1.4.1.1-9)
3. Payload round trip (Figure 1.4.1.1-10)

Also cross plotted on these figures are the capabilities of the Earth-to-Orbit Shuttle (EOS) without a Space Tug.

The missions shown are characterized by the weight of the satellite and the delta velocity requirements out of the departure orbit. The numbers by the data points designate the quantity of each type mission in the mission model. The mission model used is a compilation of anticipated NASA and DOD missions as provided by MSFC in October 1970.

The number of EOS launches required to launch and retrieve, where applicable, are denoted on the figures. The propulsion modules of the configurations shown are off-loaded in those instances where necessary to match the EOS capability. For example, the primary propulsion module for all missions originating in the polar orbit is off-loaded to fit within the EOS payload capability of 26,500 pounds to a polar orbit.

Also denoted on the figures is the constraint imposed by the EOS cargo bay length of 60 feet. To define this constraint a payload density of from two to five pounds per cubic foot was utilized. (It was assumed that the density of a specific payload was a function of its total weight.

A review of this data shows that the selected configurations have significantly more capability than is required for the majority of the lower weight payloads. This suggests that these configurations should be utilized for accomplishment of several missions per flight, i.e.:

a. Clustered payloads, or

b. Placement of some payloads with subsequent retrieval of others.

If this is not possible, off-loading of the propulsion modules can be utilized to fit the propellant loading to the specific mission requirements. This will not effect significant savings for ground-based operations but should be cost

1.4.1.1 (Continued)

effective for space based operations in conjunction with an orbiting propellant depot.

Missions Originating in 28-1/2° Inclined Orbits

As shown on Figures 1.4 1.1-2 through -4, the majority of the missions originating from the 28-1/2° inclination low earth orbit are missions to synchronous orbit. The payloads for these synchronous missions range in weight from a minimum of 250 pounds to a maximum of 10,000 pounds. Payload placement modes with reuseable Tug elements for all of these missions, will require utilization of a tandem stage configuration consisting of a primary propulsion module first stage and a primary propulsion module second stage. (These missions can be accomplished, however, with a single expendable primary propulsion module in a single launch.)

For missions with reuseable configurations, it is desirable that mission times be held to a minimum such that the same shuttle or shuttles that launch the mission components can retrieve the mission components after completion of the mission. For missions requiring multiple stages, it is probable that the EOS that launches the latter portion of the mission components can remain on orbit long enough to retrieve the first of the reuseable systems to return to orbit. With this assumption, the maximum number of EOS launches required for the most demanding placement missions would be three. At 4 million dollars per EOS launch and considering 1 million dollars refurbishment cost per tug stage, the reuseable mission cost for a two-stage reuseable tug would be 14 million dollars.

A single expendable stage (39,800 pounds capacity) could however accomplish all of the placement missions with a single launch of the EOS. The estimated recurring mission cost for an expendable propulsion module plus its astrionics module of ten million dollars is slightly less than the estimated recurring mission cost for a tandem stage reuseable configuration. The savings attributable to expendable systems are significantly larger than those reuseable missions wherein one or two additional EOS launches are required for return of the mission components to earth (i.e., 10 million dollar cost for expendable systems in lieu of a 15 to 20 million dollar cost for the reuseable tandem stage).

The remaining placement missions out of the 28-1/2° inclined orbit can be accomplished either by the EOS alone or by a reuseable stage with one primary propulsion in a single EOS launch. These missions can be accomplished more economically with the reuseable system than with the expendable system. For example, the recurring mission cost for the reuseable configuration will be 5 million dollars as opposed to a cost of 10 million dollars for the expendable configuration.

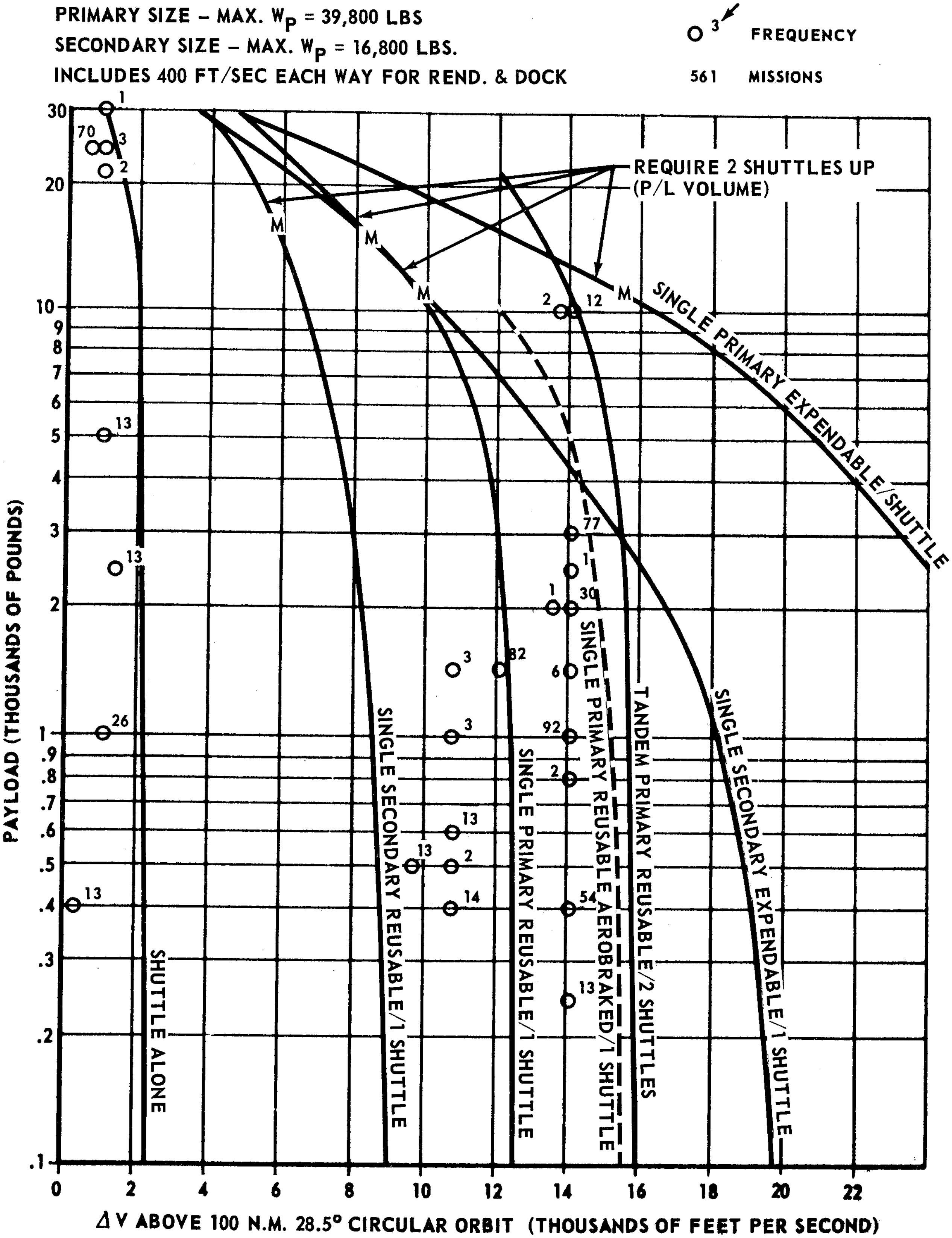


Figure 1.4.1.1-2. PAYLOAD PLACEMENT FROM 28.5° INCLINATION LOW EARTH ORBIT

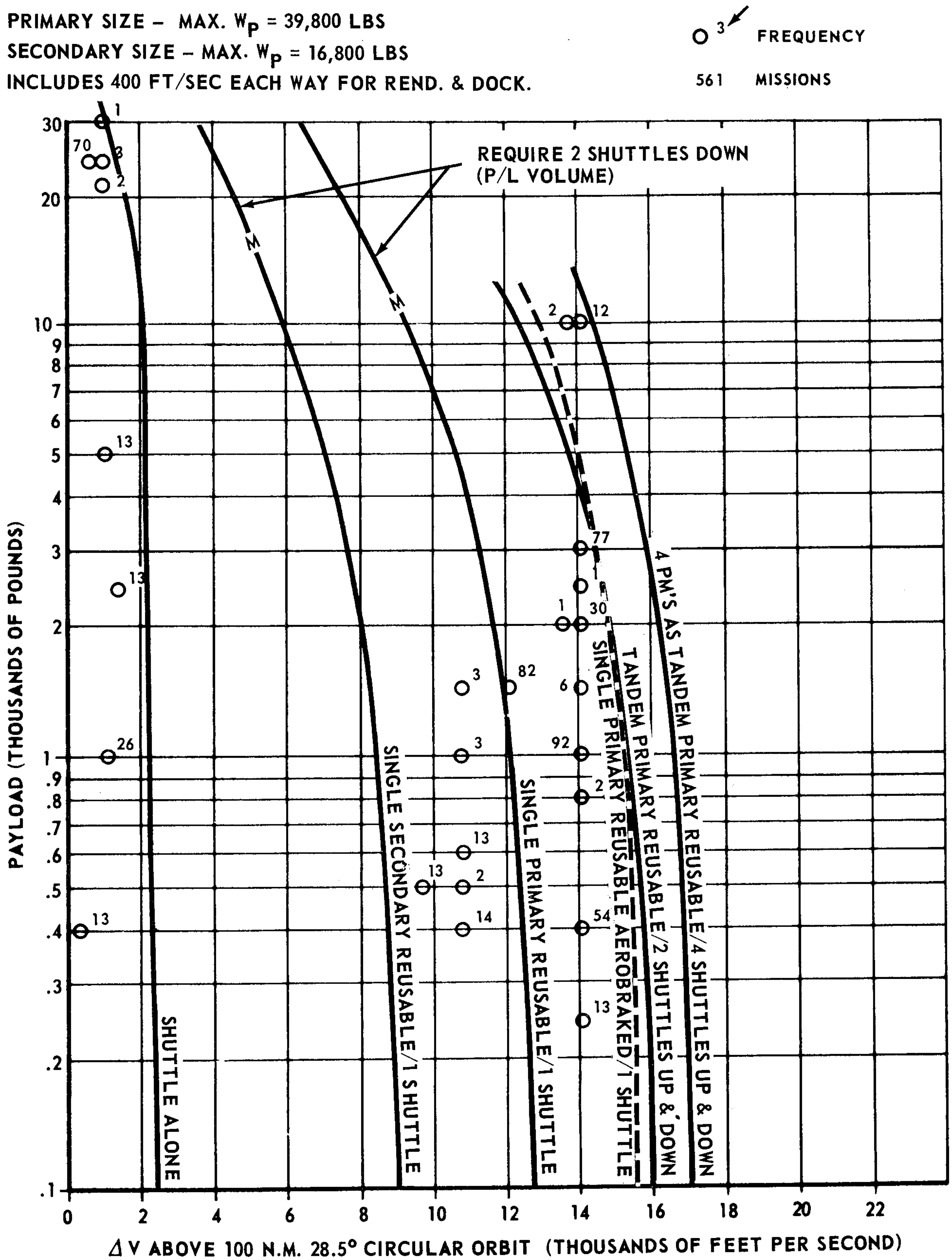


Figure 1.4.1.1-3. PAYLOAD RETRIEVAL FROM 28.5° INCLINATION LOW EARTH ORBIT

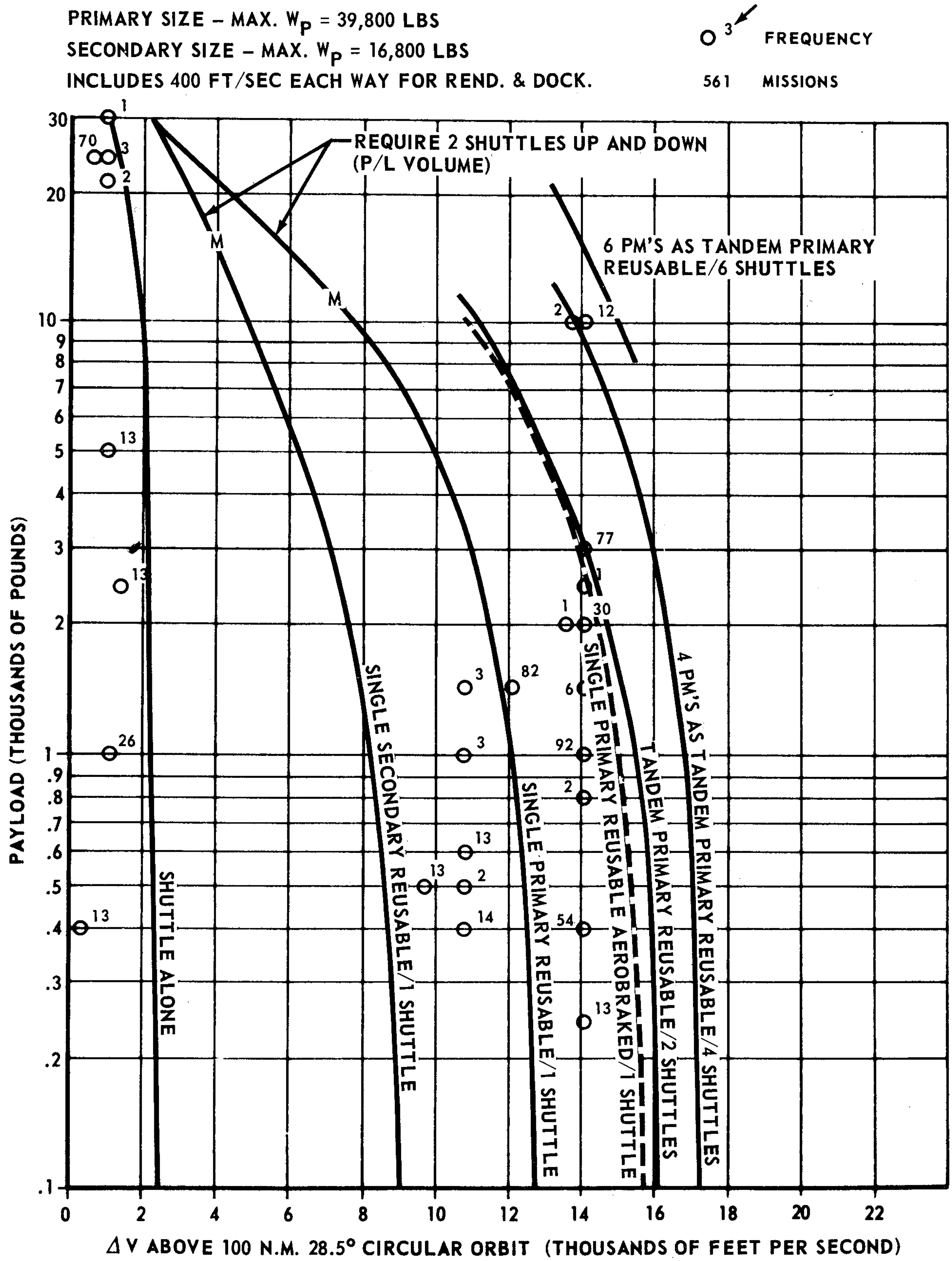


Figure 1.4.1.1-4. ROUND TRIP PAYLOAD FROM 28.5° INCLINATION LOW EARTH ORBIT

1.4.1.1 (Continued)

The retrieval missions will be more demanding than the placement mission. Again, however, all of the retrieval missions with the exception of those requiring retrieval of 10,000 pounds from synchronous orbit can be accomplished with single or tandem stage reuseable configurations. Retrieval of these payloads will require a tandem configuration consisting of two reuseable primary propulsion modules as a first stage and two reuseable primary propulsion modules as a second stage.

The most demanding missions are the round trip missions to synchronous orbit (missions wherein an identical weight payload is both delivered and retrieved in a Single Space Tug mission. Round trip of 10,000 pounds synchronous orbit payloads will require even larger configurations consisting of tandem stage vehicles with three primary propulsion modules per stage. It is of interest to note that this configuration is the same size as the combined size of a configuration for placement only of 10,000 pounds plus a configuration for retrieval of 10,000 pounds. Round trip missions for payloads of this size will therefore require the same hardware and approximately the same propellant as will two separate missions, one for placement and one for retrieval.

For missions originating in a 28-1/2^{o} inclination orbit, there is also a cluster of missions with one way delta velocity requirements of between 10,000 and 12,000 feet per second. The weights of the payloads for these missions range from 400 pounds to approximately 1500 pounds. These payloads can be placed with a single primary propulsion stage in a single shuttle launch. Retrieval of these payloads and round trip of a significant portion of these payloads can also be accomplished with a single reuseable primary propulsion module with a single shuttle launch. There are in this intermediate range, however, 82 missions with a 1500 pound payload. Round trip of these payloads will require a tandem stage configuration consisting of a primary propulsion first stage and a primary propulsion second stage.

As discussed in Paragraph 2.5.2, the capability of a single reuseable stage for high energy missions can potentially be significantly increased through utilization of an aerobraking return mode. The capability of the primary propulsion module is shown by the dotted lines on Figure 1.4.1.1-2 through -4 for reference. Because of this indicated potential it is recommended that this mode be investigated in further depth in future study activity.

No applications for the secondary propulsion module for missions originating in a 28-1/2^{o} orbit were identified.

1.4.1.1 (Continued)

Missions Originating in 55° Inclined Orbits

For the missions which originate at higher inclination orbits as shown in Figures 1.4.1.1-5 through -7, the capability of the shuttle decreases significantly, thereby requiring off-loading of the primary propulsion module to stay within this lower weight constraint. Five of the nine missions out of 55° inclination (placement, retrieval and round trip) however can be accomplished with the EOS alone or with the EOS plus a single reuseable secondary propulsion module. Because of the off-loading, accomplishment of the four higher energy missions originating in a 55° circular orbit will require a tandem stage configuration plus two shuttle launches. The first shuttle launch will carry up an off-loaded primary propulsion module and the second shuttle launch will carry up another off-loaded primary propulsion module plus the payload package. This will require assembly of these components in low earth orbit prior to mission origination. Utilization of tandem stage secondary propulsion modules will not provide sufficient capability for accomplishment of the high energy missions.

For these higher energy missions it may be more economical to bring up a single off-loaded primary propulsion module in one launch and if possible fill it with the excess EOS on-orbit maneuvering fuel or if required, fill it with fuel brought up in a second shuttle launch.

Missions Originating in Polar Orbit

As shown on Figures 1.4.1.1-8 through -10, all of the missions originating in a 90° polar orbit with the exception of one placement and ten retrievals can be accomplished with an off-loaded primary propulsion module in a single shuttle launch. All of these missions can also be accomplished with a secondary propulsion module in a single launch of the shuttle. These limited applications for the secondary propulsion may not justify the development of the secondary propulsion module. Additional operational interface and economic trades considering manned earth orbit mission applications are required to further investigate the desirability of the secondary propulsion module.

1.4.1.2 Unmanned Earth Orbit Missions - Space Based

For accomplishment of the unmanned earth orbit missions using a space based mode of operations, it will be desirable to use the same configurations discussed above. While space based operations will allow use of larger (and therefore more efficient, i.e.: improved mass fraction) Space Tug propulsion modules, the payload capability of the EOS as a tanker must be considered. A large reuseable single stage (77,000 pounds of propellant capacity with a mass fraction of 0.89) can, for example, place 10,000 pounds of payload in orbit. This large

1.4.1.2 (Continued)

MEDIUM SIZE – MAX. W_P = 29(800 LBS

SMALL SIZE – MAX. W_P = 16,800 LBS.

INCLUDES 400 FT/SEC EACH WAY FOR REND. & DOCKING

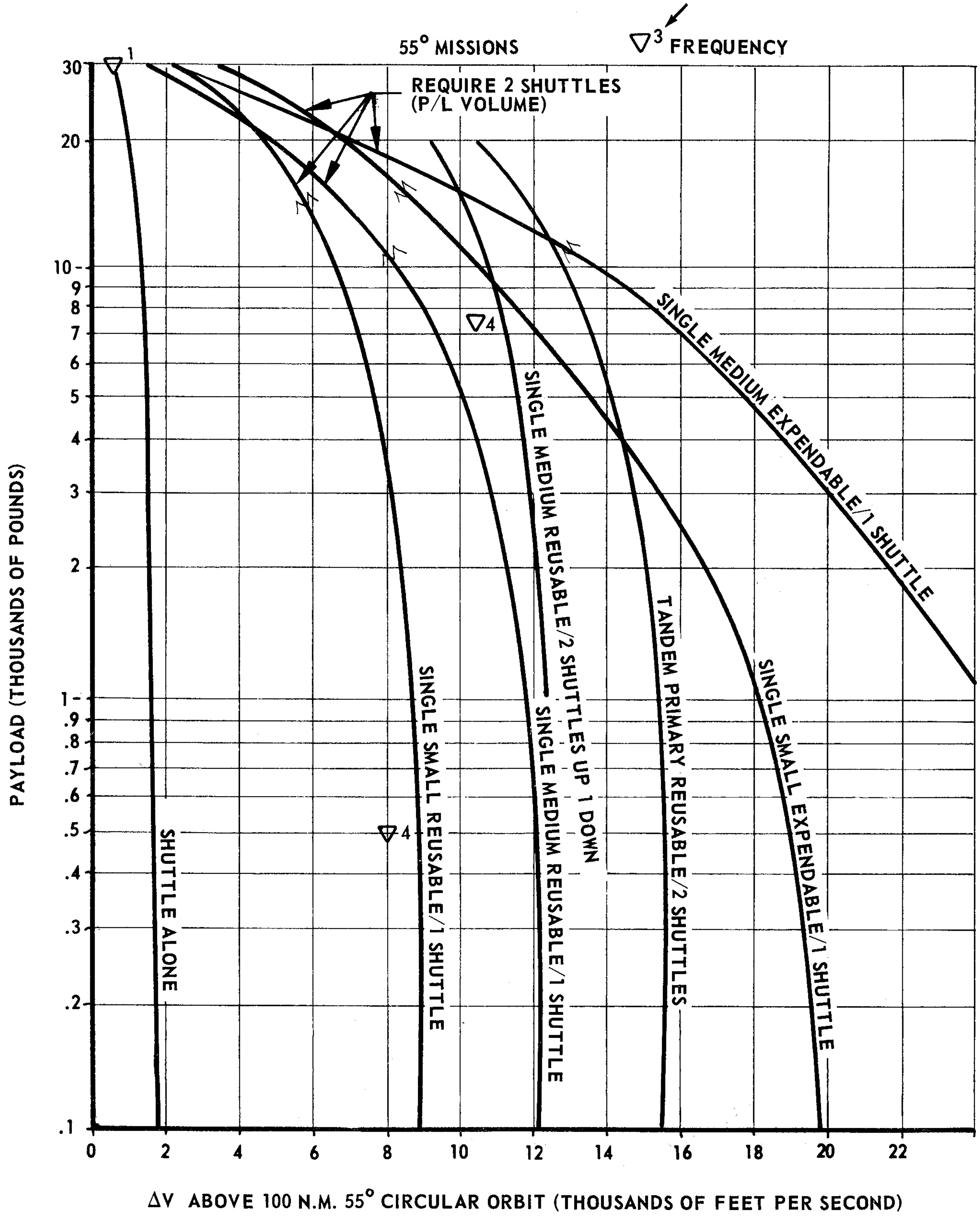


Figure 1.4.1.1-5. PAYLOAD PLACEMENT FROM 55° INCLINATION LOW EARTH ORBIT

1.4.1.2 (Continued)

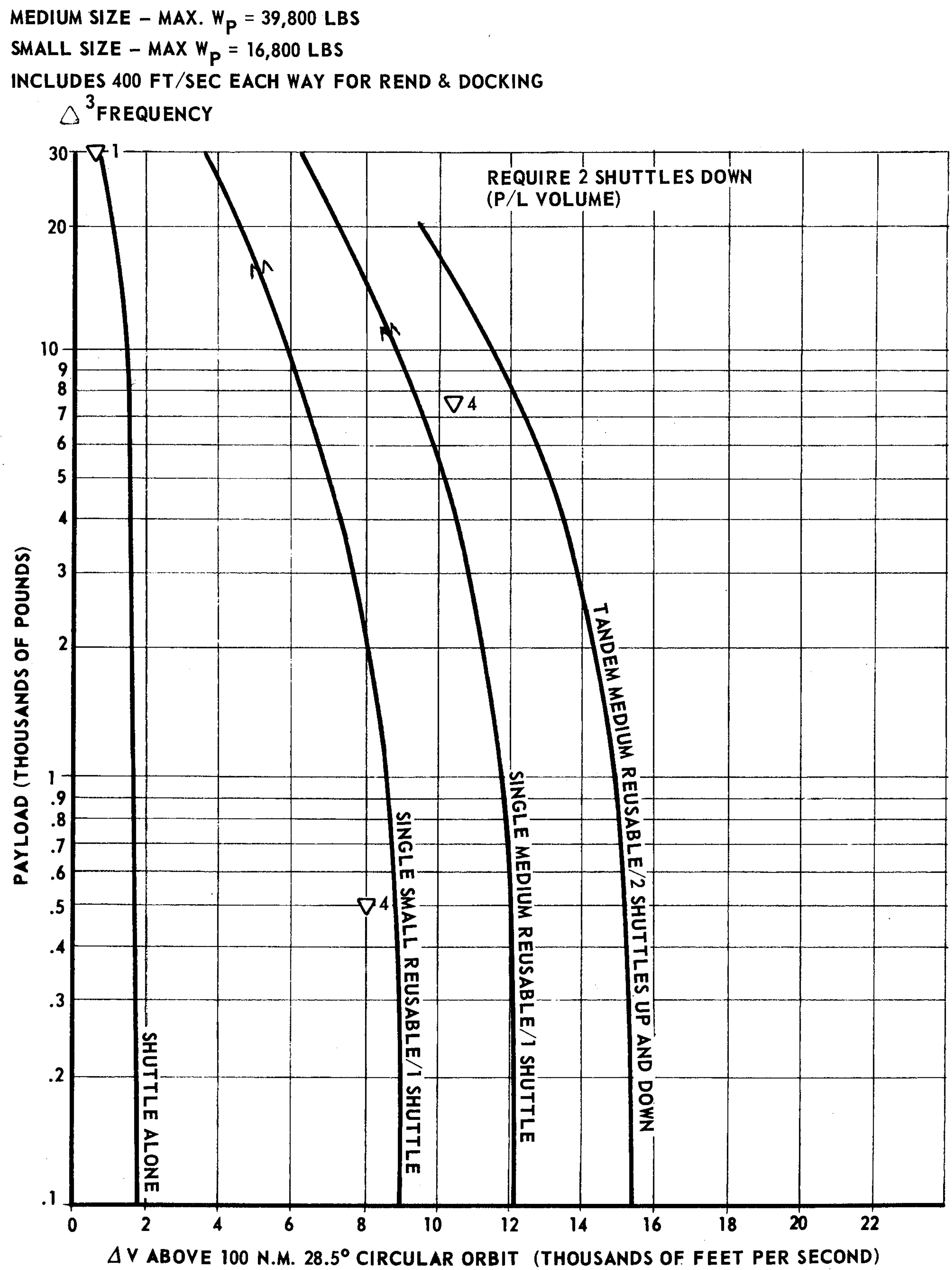


Figure 1.4.1.1-6. PAYLOAD RETRIEVAL FROM 55° INCLINATION LOW EARTH ORBIT

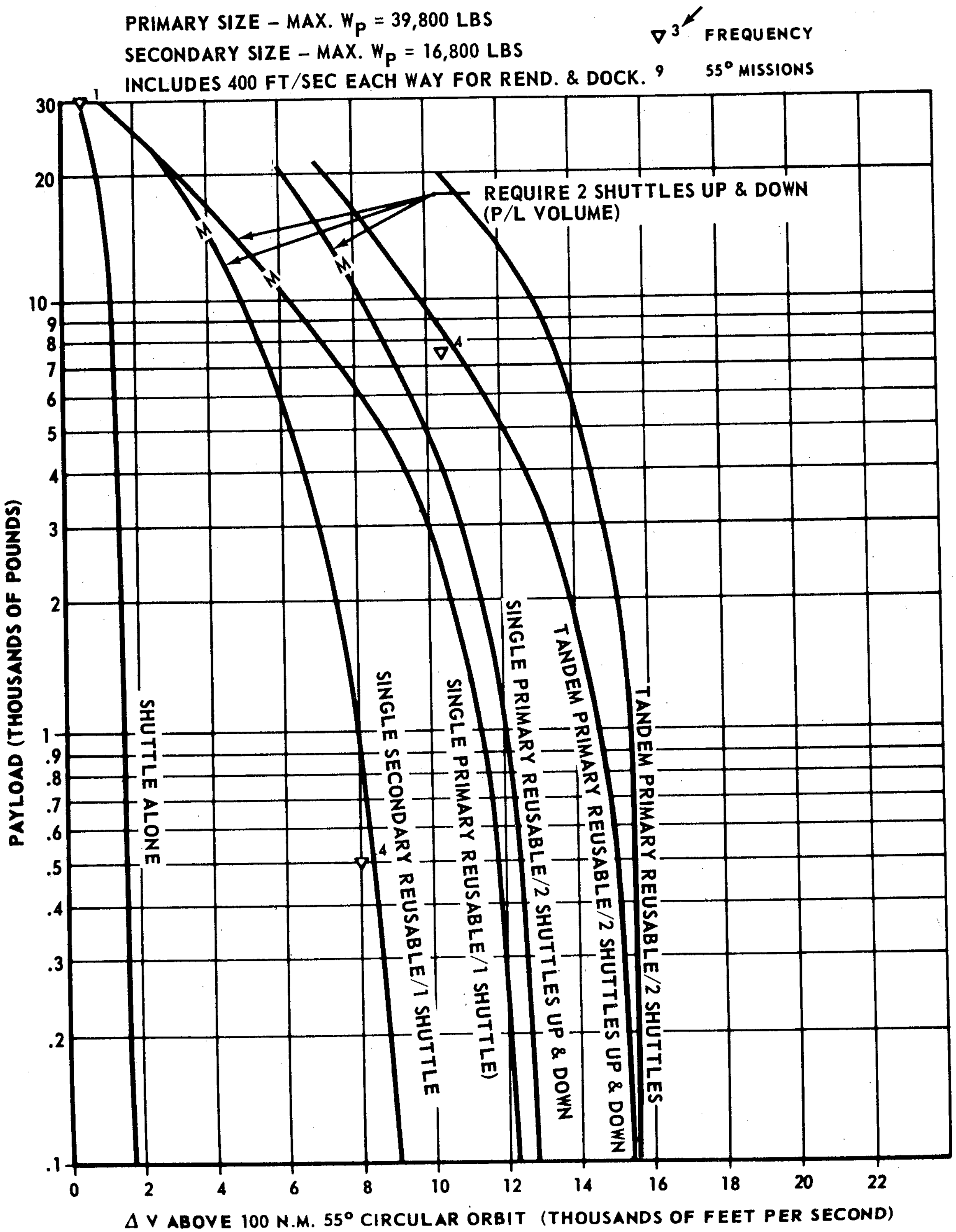


Figure 1.4.1.1-7. ROUND TRIP PAYLOAD FROM 55° INCLINATION LOW EARTH ORBIT

1.4.1.2 (Continued)

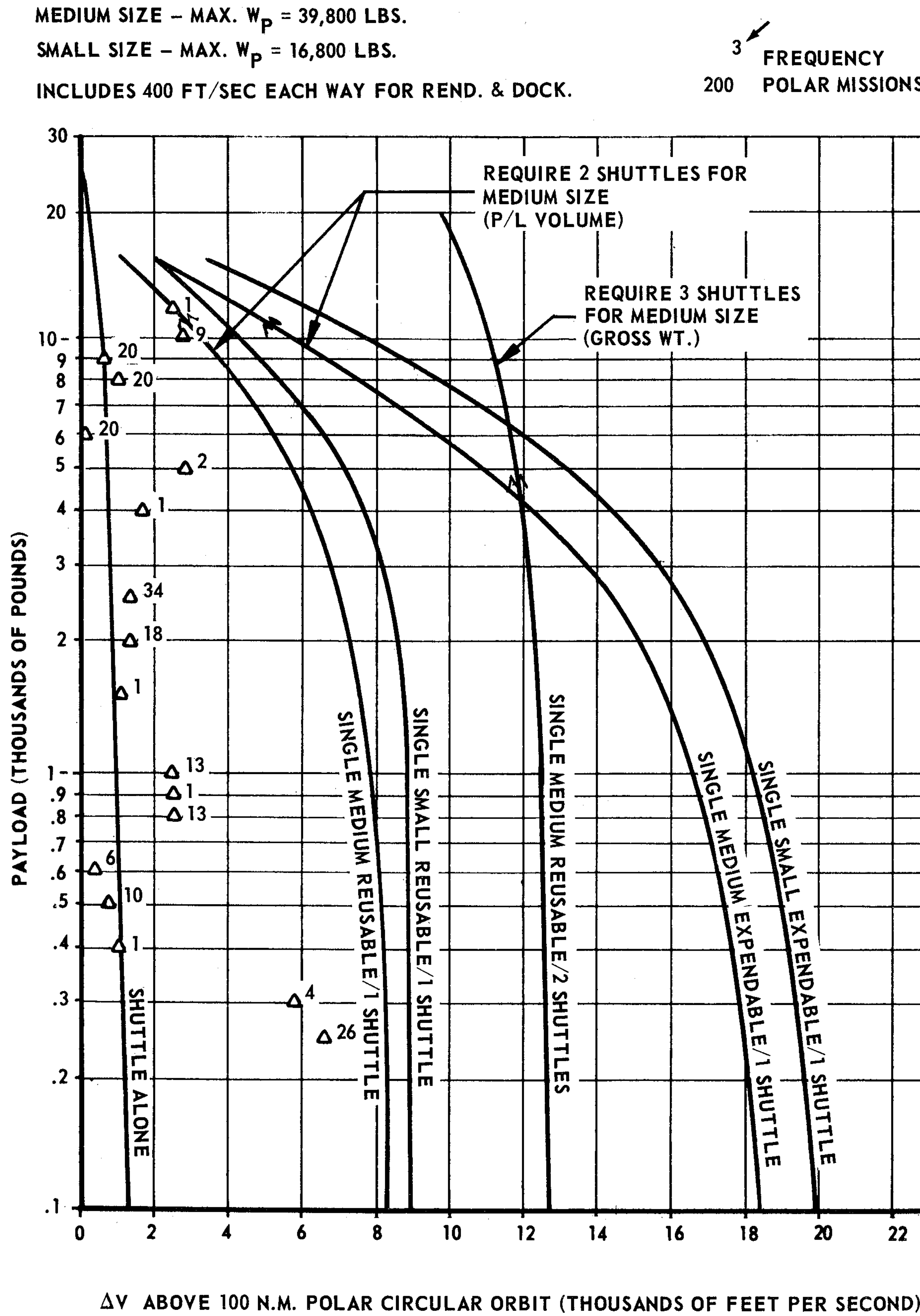


Figure 1.4.1.1-8. PAYLOAD PLACEMENT FROM 90° INCLINATION LOW EARTH ORBIT

MEDIUM SIZE – MAX. W_P = 29,800 LBS.
SMALL SIZE – MAX. W_P = 16,800 LBS.
INCLUDES 400 FT/SEC EACH WAY FOR REND. & DOCK.

△ 3 FREQUENCY
200 POLAR MISSIONS

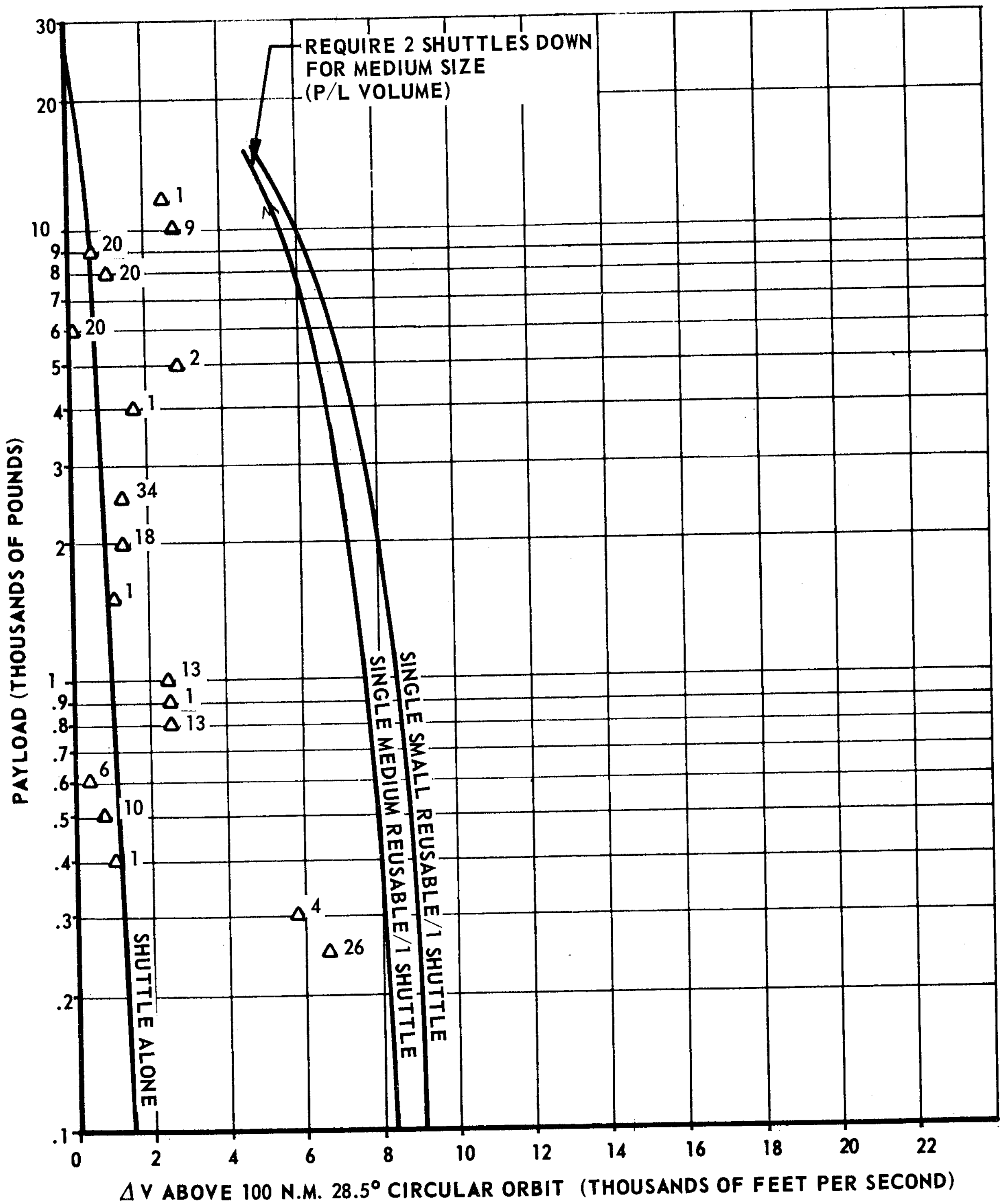


Figure 1.4.1.1-9. PAYLOAD RETRIEVAL FROM 90° INCLINATION LOW EARTH ORBIT

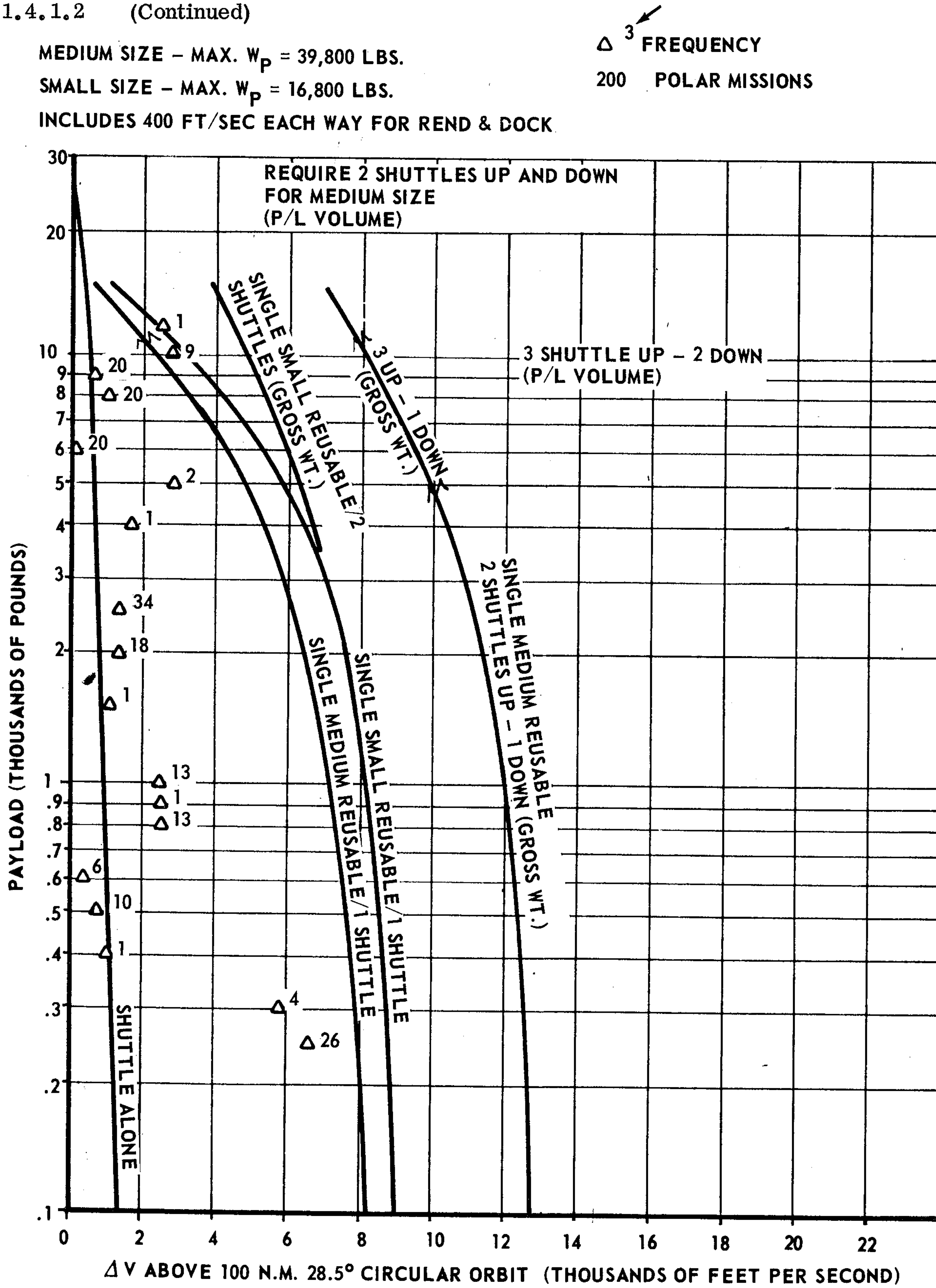


Figure 1.4.1.1-10. ROUND TRIP PAYLOAD FROM 90° INCLINATION LOW EARTH ORBIT

1.4.1.2 (Continued)

stage can retrieve approximately 5,000 pounds of payload from synchronous orbit but could not provide synchronous orbit round trip capability. For direct fueling by the EOS, a maximum tank mass fraction of 0.95 may be assumed. This will provide a delivery capability of the EOS to a 28^{o} inclination low earth orbit of 0.95 x 54,000 pounds or 51,000 pounds. Two shuttle launches will therefore be required for fueling, i.e.: 77,000÷51,000 = 1+ (2 Tugs) If an Orbiting Propellant Depot is utilized, and there is no appreciable boil-off or transfer losses, an equivalent of 1-1/2 launches of an EOS will suffice. This stage is too large for effective accomplishment of most of the other earth orbit missions and requires utilization in an off-loaded condition which negates its mass fraction advantage.

The synchronous placement mission, can be accomplished, however, with a reuseable two-stage configuration (39,800 pounds of propellant per stage) with two EOS launches to place the mission components in the departure orbit. Further, it can be accomplished with an expendable stage with a 39,800 pound propellant capacity. It, therefore, appears reasonable to use the smaller more flexible (39,800 pound capacity) stage, which requires less off-loading for low energy missions, for both ground based and space based unmanned earth orbit mission applications.

1.4.1.3 Earth Orbit Support Missions-Ground and Space Based

The Space Tug earth orbit support missions will include:

a. Maneuver and/or assembly of components for other spacecraft, satellites Space Stations, Space Bases, etc.

b. Crew rotation and resupply of Space Station and/or Space Bases.

c. Propellant delivery from the EOS to the OPD.

Each of these missions can be accomplished using either a ground based or space based mode of operations. The following Space Tug elements can be utilized to provide the desired configurations.

a. The reuseable primary propulsion module (39,800 pounds of propellant capacity) as designed for earth orbit operations. This module may be used in an off loaded condition for the lower energy missions.

b. The reuseable secondary propulsion module (16,800 pounds of propellant capacity, off-loaded as required).

1.4.1.3 (Continued)

c. The reuseable astrionics module defined for earth-orbit operations-with plug in kits as required for specific mission applications.

d. The crew module outfitted as required for the various missions, i.e.:

 1. Maneuver and assembly operations (3 men for 7 days) - 6607 pounds

 2. Crew rotation (15 men 2 day) - 9386 pounds

 3. Manned reconnaisance (3 men 14 days) - 7136 pounds

e. A cargo module which uses the empty shell of the crew module.

f. Manipulator and/or docking adapter arm kit - these kits are not defined, but an inert weight penalty of 200 pounds each was allowed to provide for this contingency.

The various configurations for accomplishment of the earth orbit supports missions using a secondary propulsion module are shown in Figure 1.4.1.3-1. Figures 1.4.1.3-2 and -3 show the payload capabilities of the EOS alone and of the various EOS/Tug configurations for performance of the following missions to 55° and 28° inclination, 270 N.M. orbits: The missions as represented by the symbols on the figures are described below.

a. EOS (without Tug) - 1 to 7 Day Missions

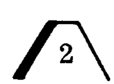
 1. Cargo placement (no passengers) - 

EOS ascends direct to target orbit with cargo and returns to earth empty.

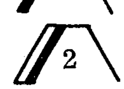
 2. Cargo Round Trip (No passengers) 

 3. Cargo and Passengers Round Trip 

b. Tug/EOS-Cargo Placement - 2 Day Missions

 1. Ground Based Tug/EOS - 

Unmanned

 - 

Manned

For this mission, the Tug plus cargo (and passengers in crew module as applicable) is launched from earth in the EOS cargo bay. At the 100 N.M. orbit the Tug is deployed for subsequent delivery of payload to the 270 N.M. orbit. The EOS remains on orbit. The Tug transfers its cargo and returns to 100 N.M. orbit. The empty Tug is

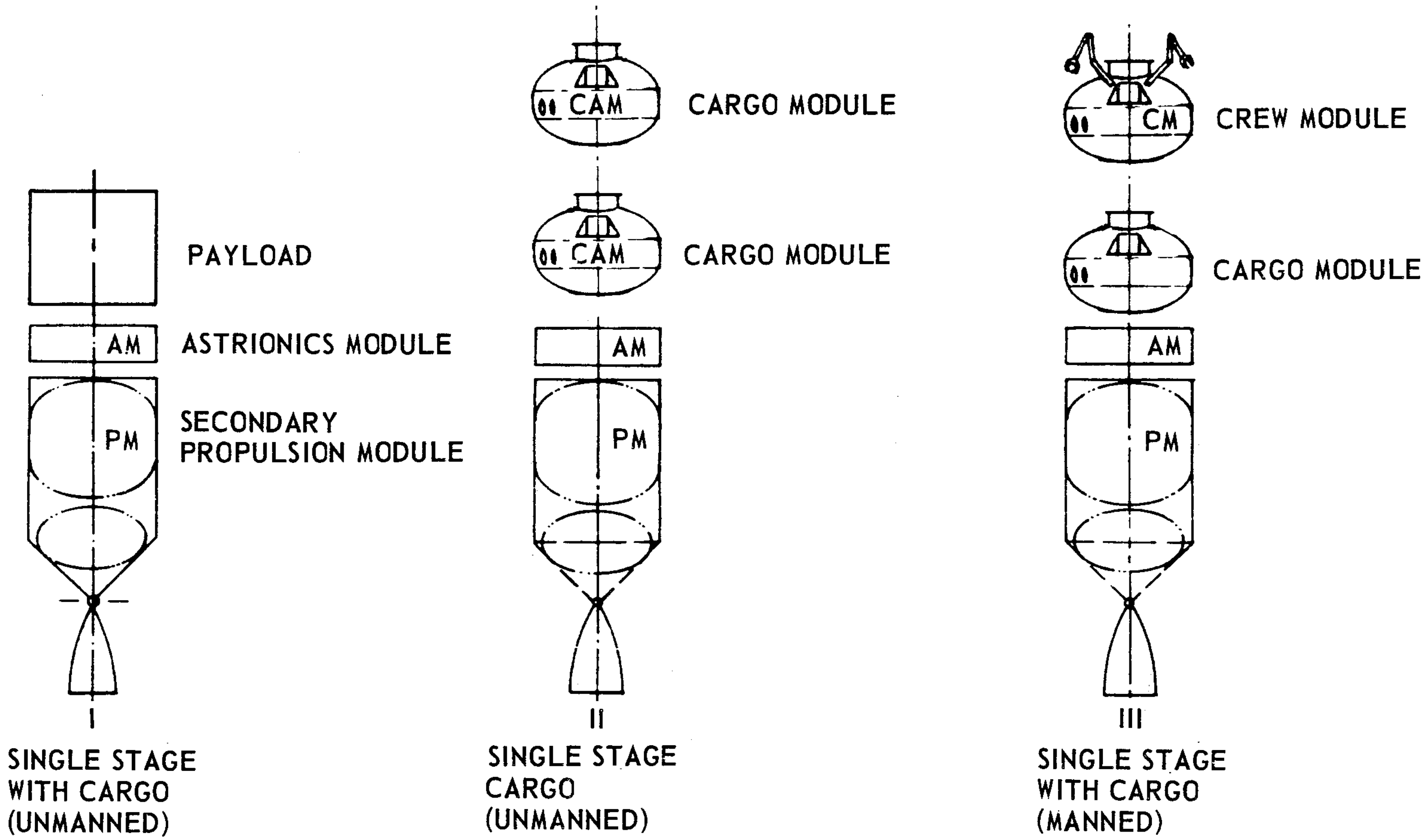


Figure 1.4.1.3-1. CONFIGURATIONS FOR SUPPORT OF MANNED EARTH ORBIT MISSIONS

1.4.1.3 (Continued)

loaded into the waiting EOS and returned to earth.

2. Space Based Tug/EOS - 

Unmanned

- 

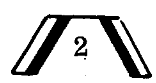
Manned

For this mission the unmanned empty Tug (without a crew module) descends from the 270 N.M. orbit and meets the EOS in the 100 N.M. orbit. Cargo (and passengers in crew module, where applicable) is transferred to the Tug for subsequent return to the 270 N.M. orbit. The maximum time of two days allotted for this mission may in the worst case (as depicted) require the Tug to perform plane changes totaling 3^{o} to account for nodal regressions between orbits.

c. Tug/EOS-Cargo Round Trip - 2 Day Mission

1. Ground Based Tug/EOS 

Unmanned



Manned

For this mission, the mission profile is identical to that shown in b.1. through the delivery of the payload delivery to the 270 N.M. orbit. After the payload has been transferred to the Space Station, a return payload (cargo and/or crew and crew module) is transferred to the Tug. The Tug descends to the 100 N.M. orbit and the Tug and its cargo are loaded into the on-orbit waiting EOS which then returns to earth. The Tug plane change requirements for this mission are identical to that for cargo placement missions i.e., three degrees due to nodal regression.

2. Space Based Tug/EOS 

Unmanned

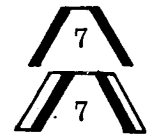
Manned

For this mission, the Tug in its 270 N.M. parking orbit picks up a payload (cargo and/or crew and crew module) also located in a 270 N.M. orbit. The Tug descends to a 100 N.M. orbit for rendezvous with the EOS. The EOS delivers a payload (cargo and/or crew and crew modules) to 100 N.M. orbit where the EOS and Tug exchange payloads. The EOS returns its payload to the earth's surface. The Tug delivers its payload to the 270 N.M. orbit. During this mission profile, the Tug will undergo two plane changes totaling no more than three degrees.

1.4.1.3 (Continued)

d. Tug/EOS Cargo Round Trip - 7 Day Missions

1. Ground Based Tug/EOS

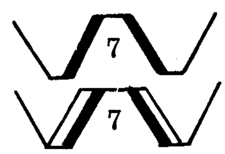


Unmanned

Manned

This mission profile is identical to the ground based Tug/EOS mission profile shown above in c.1. However, when the payload is delivered to 270 N.M., a five day on orbit duration has been planned to permit Tug and/or other operations at the upper orbit. This lengthens the total mission time to seven days. The longer duration of this mission and the resulting increased nodal regression of the 100 and 270 N.M. orbits necessitates the Tug making plane changes totaling seven degrees.

2. Space Based Tug/EOS



Unmanned

Manned

For this mission the initial portion of the mission profile is identical to that shown in b.2. above, for placement of payload in the 270 N.M. orbit. After the payload is transferred to the Space Station a return payload (cargo and/or crew module plus crew) is transferred to the Tug. Five days are allowed for these transfers. The Tug then descends to 100 N.M. orbit and transfers the return payload to the on-orbit, waiting EOS. The EOS then returns to earth and the empty Tug returns to the 270 N.M. orbit. This is the most practical mission for crew transfer in that it allows the old crew and the new crew to mutually occupy the Space Station for approximately 5 days. The total time for this mission is approximately 7 days. During this mission the Tug must perform four plane changes. These are one and two degree plane changes during the initial trip from 270 to 100 and back to 270 N.M. orbit. The plane changes, due to nodal regressions, significantly increase the energy requirements.

For the above mission and mission modes, the Tug cargo capabilities were defined for Space Station support. Figures 1.4.1.3-2 and -3 summarizes the manned and unmanned capabilities for payload placement and round trip missions to 55° and 28°, 270 n.m. orbits, respectively.

As shown in Figure 1.4.1.3-2 for the manned 55° missions, the Shuttle can deliver 12,713 pounds of cargo (plus crew, crew module and a single cargo module) and return an equal payload to earth within 7 days. Ground and space based Tug/EOS combinations can deliver 17,700 pounds and 32,713 pounds of cargo respectively when operating in a round trip, 2 day mission mode. The

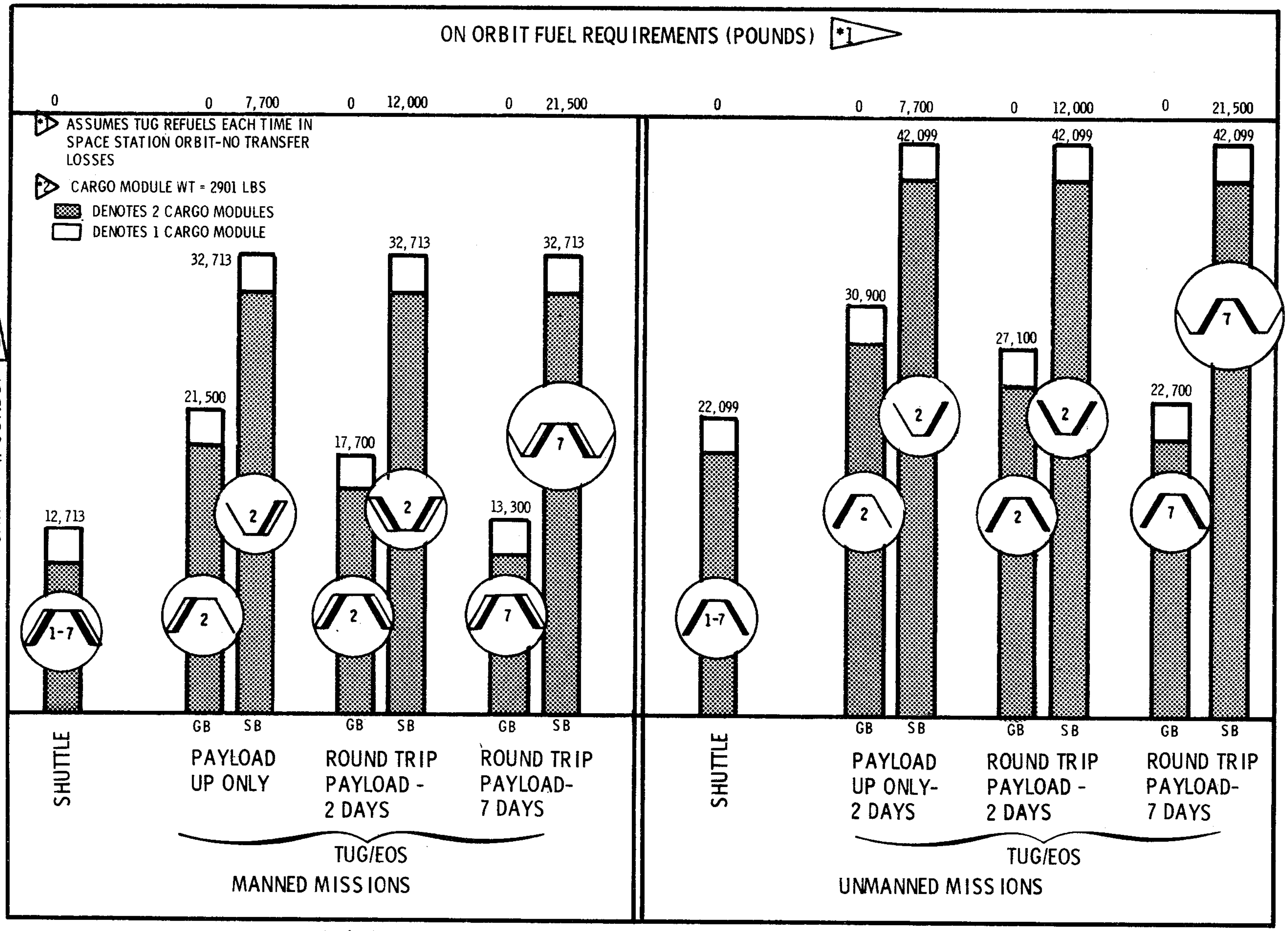


Figure 1.4.1.3-2. CAPABILITIES OF SECONDARY PROPULSION MODULE FOR 55° INCLINATION 270 N.M. SPACE STATION SUPPORT

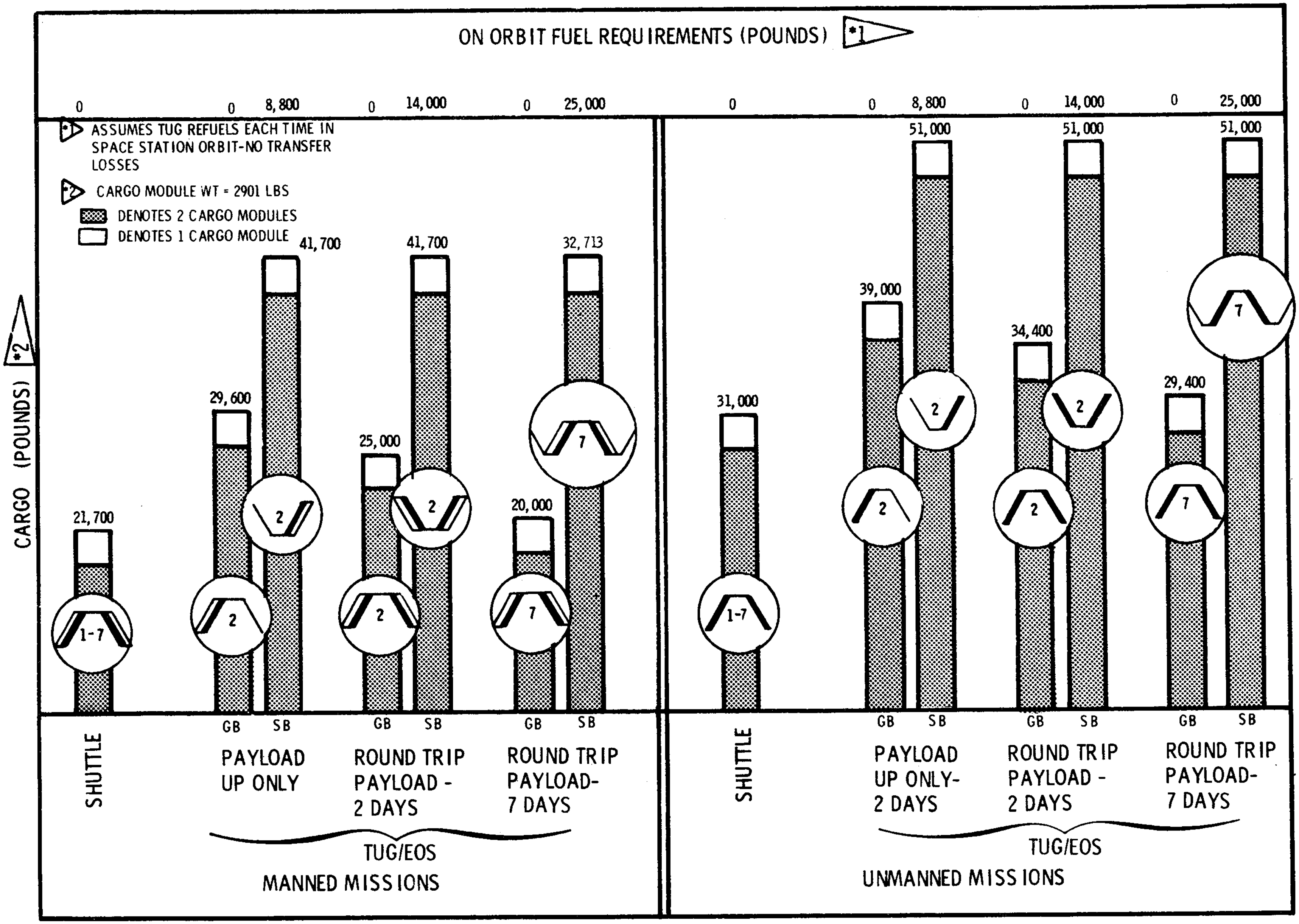


Figure 1.4.1.3-3. CAPABILITIES OF SECONDARY PROPULSION MODULE FOR 28.5° INCLINATION 270 N.M. SPACE STATION SUPPORT

cargo capability of the space based Tug/EOS is established by the cargo capability of the EOS to the lower 100 n.m. orbit of 45,000 pounds i.e. 45,000 pounds less crew module and crew weight of 9386 pounds less single cargo module weight of 2901 pounds equals 32,713 pounds. The cargo capability of the space-based-Tug/EOS is dependent on on-orbit fuel at 270 n.m. for refueling. If the mission duration is increased to 7 days duration, the cargo capability of ground-based-Tug/EOS is decreased to 13,300 pounds and the cargo capability for the space-based Tug/EOS remains at 32,713 pounds (assuming additional on-orbit OPD propellant for refueling).

For the unmanned missions, the Shuttle can deliver 22,099 pounds of cargo (plus a single cargo module) to a 55° inclination, 270 n.m. orbit. Space and ground based Tug/EOS combinations can deliver 42,099 and 27,100 pounds of cargo, respectively, when operating in a round trip, 2 day mission mode. If the mission duration increases to 7 days duration, the cargo capability decreases to 22,700 gor the ground based Tug/EOS but remains at 42,099 pounds for the space-based-Tug/EOS. As shown above, the space based payload remains the same only if on orbit propellant can be used for refueling.

Figure 1.4.1.3-4 summarizes the data shown in Figures 1.4.1.3-2 and -3 to compare payload capabilities for the EOS to that of the EOS/Tug operating in a space and ground based mode. The ground based mode payload capability is also compared to the space based mode payload capability. These comparisons were conducted for both payload and round trip payloads. (Two day space based missions are also shown for reference.)

This figure shows that:

a. The Tug/EOS cargo capabilities are much larger than those of the EOS alone.

b. The Tug/EOS payload capability decreases with mission time due to increase propellant requirements to compensate for orbital regression. For example, for mission times of seven days, the payload capability of the EOS alone is approximately equivalent to the ground based Tug/EOS.

c. The space based mode is the most economical mode if the Tug can use "free" propellant from an OPD. "Free" propellant assumes that the excess EOS on-orbit maneuvering propellant and/or EOS excess cargo capability is used to replenish the OPD. If the fuel is not "free", the net cargo capabilities, as shown on the lower portion of the figure, will result.

MISSIONS	COMPETITIVE MODES A	COMPETITIVE MODES B	CREW ROTATION PLUS CARGO — SPACE STATION ORBIT 28° Δ POUNDS A-B	CREW ROTATION PLUS CARGO — 28° % $\frac{A-B}{B}$ X 100	CREW ROTATION PLUS CARGO — 55° Δ POUNDS A-B	CREW ROTATION PLUS CARGO — 55° % $\frac{A-B}{B}$ X 100	CARGO ONLY — SPACE STATION ORBIT 28° Δ POUNDS A-B	CARGO ONLY — 28° % $\frac{A-B}{B}$ X 100	CARGO ONLY — 55° Δ POUNDS A-B	CARGO ONLY — 55° % $\frac{A-B}{B}$ X 100
GROSS PAYLOAD PLACEMENT	SB	EOS	+20,000	+88%	+20,000	+146%	+20,000	+64%	+20,000	+91%
	SB	GB	+12,100	+40%	+11,200	+50%	+12,100	+31%	+11,200	+36%
	GB	EOS	+7,900	+35%	+8,800	+64%	+7900	+25 %	+8,800	+40%
NET PAYLOAD ROUND TRIP *1	SB	EOS	+6000	+26%	+8000	+58%	+6000	+19%	+8000	+36%
	SB	GB	+2700	+10%	+3000	+16%	+2700	+8%	+3000	+11%
	GB	EOS	+3300	+15%	+5000	+36%	+3300	+11%	+5000	+23%
	SB	EOS	-5000	-22%	-1500	-11%	-5000	-16%	-1500	-7%
	SB	EOS	+3000		+6500	47%	+3000	+10%	+6500	+29%
	SB	GB	-300		+1500	8%	-300	-1%	+1500	+6%

*1 ASSUMES NO PROPELLANT BOIL-OFF OR TRANSFER LOSSES FOR SPACE BASED MODE. ALSO ASSUMES NO EOS PROPELLANT RESERVES USED.

Figure 1.4.1.3-4. SPACE TUG/EOS FOR SPACE STATION SUPPORT MISSIONS

1.4.2 Lunar Landing Missions (Manned and Unmanned)

The planned manned and unmanned Space Tug lunar landing missions (which will originate and end in a 60 n.m. polar lunar orbit) are as follows:

a. Unmanned coplanar placement of cargo on the lunar surface.

b. Coplanar landing and return of men and cargo.

c. Emergency missions for abort and/or rescue of crew from the lunar surface.

The Space Tug elements which can be used to assemble the necessary configurations are as follows:

a. The primary propulsion module (39,800 pounds propellant capacity) as insulated and shielded for the lunar mission.

b. The astrionics module configured for the lunar landing missions.

c. The multipurpose crew module outfitted for three men to 50 days.

d. The doughnut cargo module half sections.

e. The landing leg kit.

f. The auxiliary power system (weight = 2145 pounds) - considered as cargo.

g. The manipulator arms kit.

h. The environmental protection kit for a 50 day mission.

i. The radar kit for lunar landing operations.

j. The RCS booster kit for increase control thrust.

Representative configurations to perform the lunar landing missions are shown in Figure 1.4.2.0-1.

The configuration for coplanar delivery of the large unmanned payloads consists of the primary propulsion module, the landing leg kit, the astrionics module, the various kits, the payload and, when required, the doughnut cargo module. The doughnut cargo module will be adequate to carry most of the cargo required for lunar experiments (See Appendix A). The larger cargo elements, will be carried to the lunar surface in their separate and unique packaging. By necessity, these large bulky payloads will require mounting above the propulsion module and will, therefore, be approximately 50 feet above the lunar surface

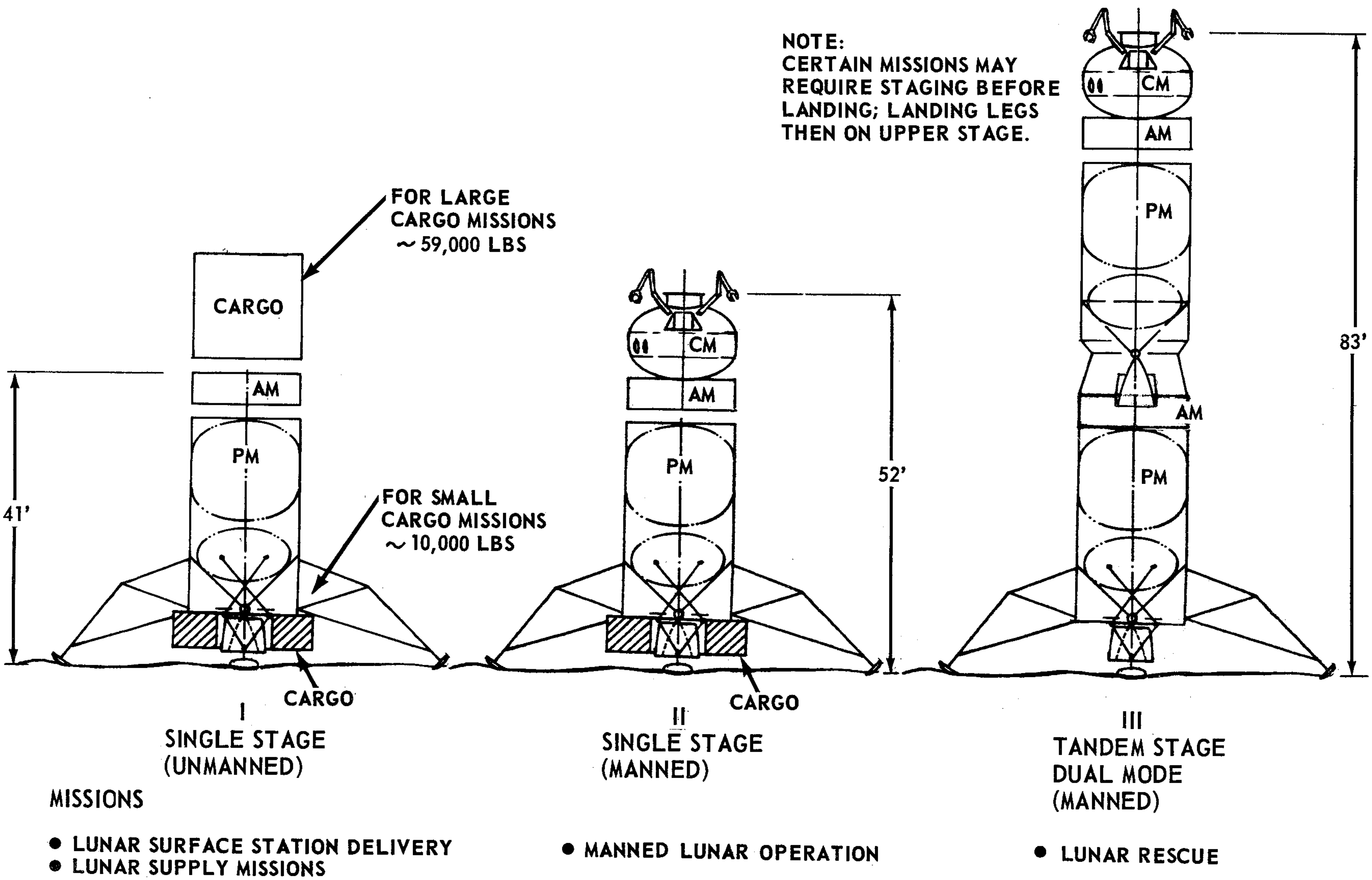


Figure 1.4.2.0-1. CONFIGURATIONS FOR LUNAR LANDING MISSIONS

when the tug is landed. This will present a major unloading problem. For utilization of these large payloads on the lunar surface a lifting and handling device must be provided. This same device could be used to remove the large cargos from the Space Tug.

The capability of this configuration to deliver cargo unmanned to the lunar surface is shown in Figure 1.4.2.0-2. A maximum cargo of 59,000 pounds can be delivered to the lunar surface if the Tug is left on the surface for subsequent refueling before returning to orbit. If the Tug delivers cargo and returns without refueling the cargo capability is reduced to 41,000 pounds. A maximum of 59,000 pounds can be delivered in the expendable mode.

The manned coplanar landing and return missions can be accomplished by a configuration, as shown in the center of Figure 1.4.2.0-1 consisting of the primary propulsion module, with landing legs, the astrionics module, the crew module, the doughnut shaped cargo module, and the various kits discussed above. The weight of cargo carried to the lunar surface may be traded against the weight of cargo carried back to the LOSS. The cargo capability of this configuration for these various conditions is shown in Figure 1.4.2.0-3. Crew module and crew will go down and back in all instances, weights for these items are not reflected in the figure.

This configuration can also be used to accomplish some emergency missions. For example, if less than the maximum cargo is delivered some plane change for an abort return (with crew module but no cargo module) can be made. Figure 1.4 2.0-4 shows the abort return plane change capability from the lunar equator as a function of cargo down coplanar to the lunar equator.

An emergency rescue mission, considering the worst case of a 90^o plane changes to and from the lunar surface, would require multistage configurations. The energy requirement, however, can be reduced by using a rescue-and-wait mode. In this mode an immediate descent is made to the lunar surface. The crew to be rescued transfers to the rescue vehicle crew module and waits until the angle between the landing site and the LOSS is small enough to permit the return flight to the LOSS. The worst design condition for this mode is 90^{o}plane change to the lunar equator and can be satisfied with a two stage reuseable configuration as shown to the right of Figure 1.4.2.0-1. This configuration can reach any point on the lunar surface. The rescue waiting period is dependent upon the staging method.

One method is to separate the final stage before landing. It returns to the LOSS while the second stage lands and performs the rescue. The vehicle capability for this method is shown in Figure 1.4.2.0-5 on the curve labeled. "Tandem - One Stage Fly By". The alternative method is to separate both stages before landing both stages. The second stage performs the rescue and returns as soon as possible while the first stage waits until it can return co-planar. The

CONFIGURATION	PAYLOAD PLACEMENT ON SURFACE (LBS)	
	TUG REMAINS ON SURFACE	TUG RETURNS TO LOSS
WITHOUT DOUGHNUT CARGO MODULE	59,000	41,000
WITH DOUGHNUT CARGO MODULE	54,700	34,000 (RETURNS CARGO MODULE) 39,000 (LEAVES CARGO MODULE)

Figure 1.4.2.0-2. UNMANNED LUNAR MISSIONS

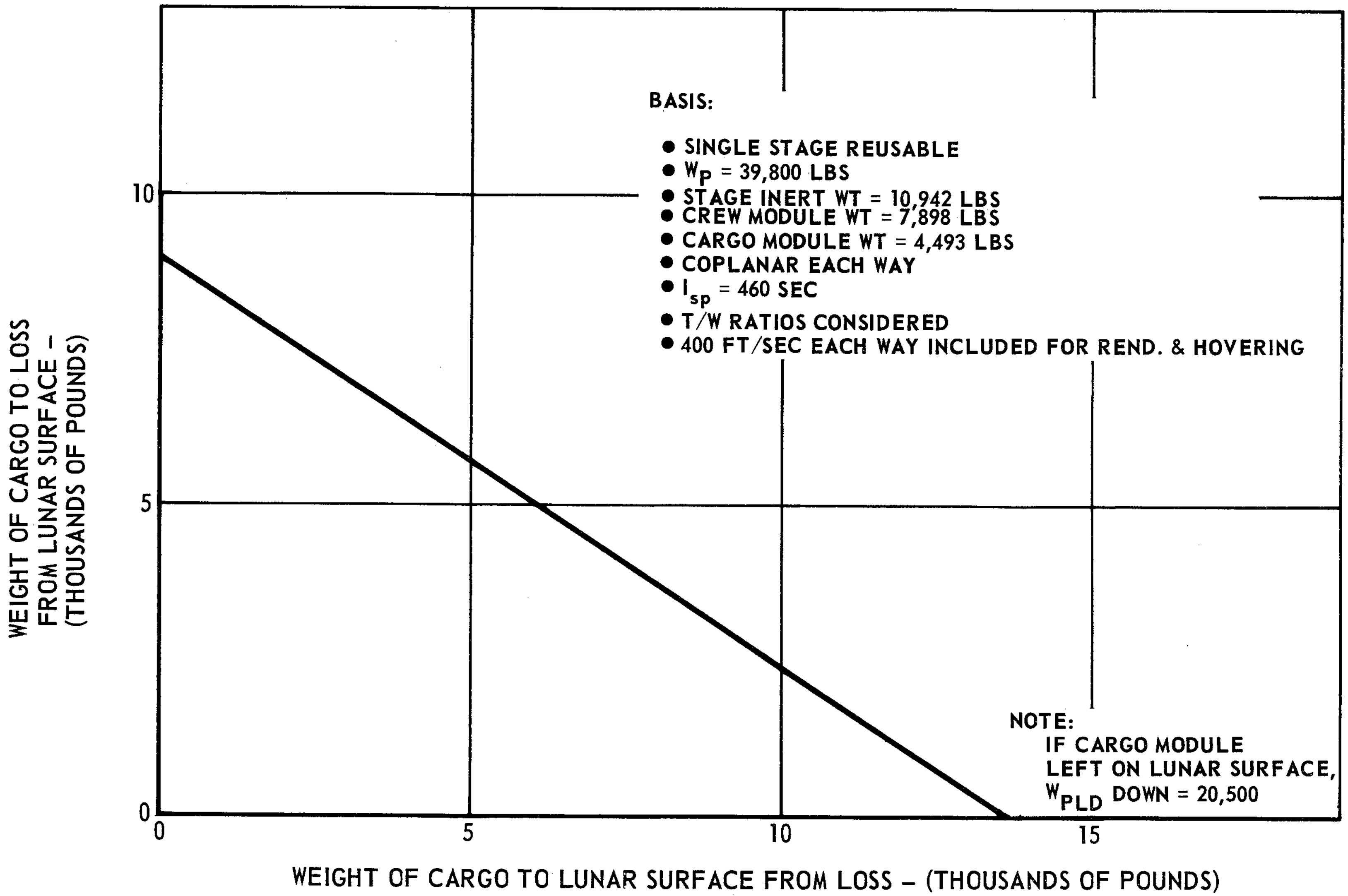


Figure 1.4.2.0-3. MANNED COPLANAR LUNAR LANDING CARGO CAPABILITY

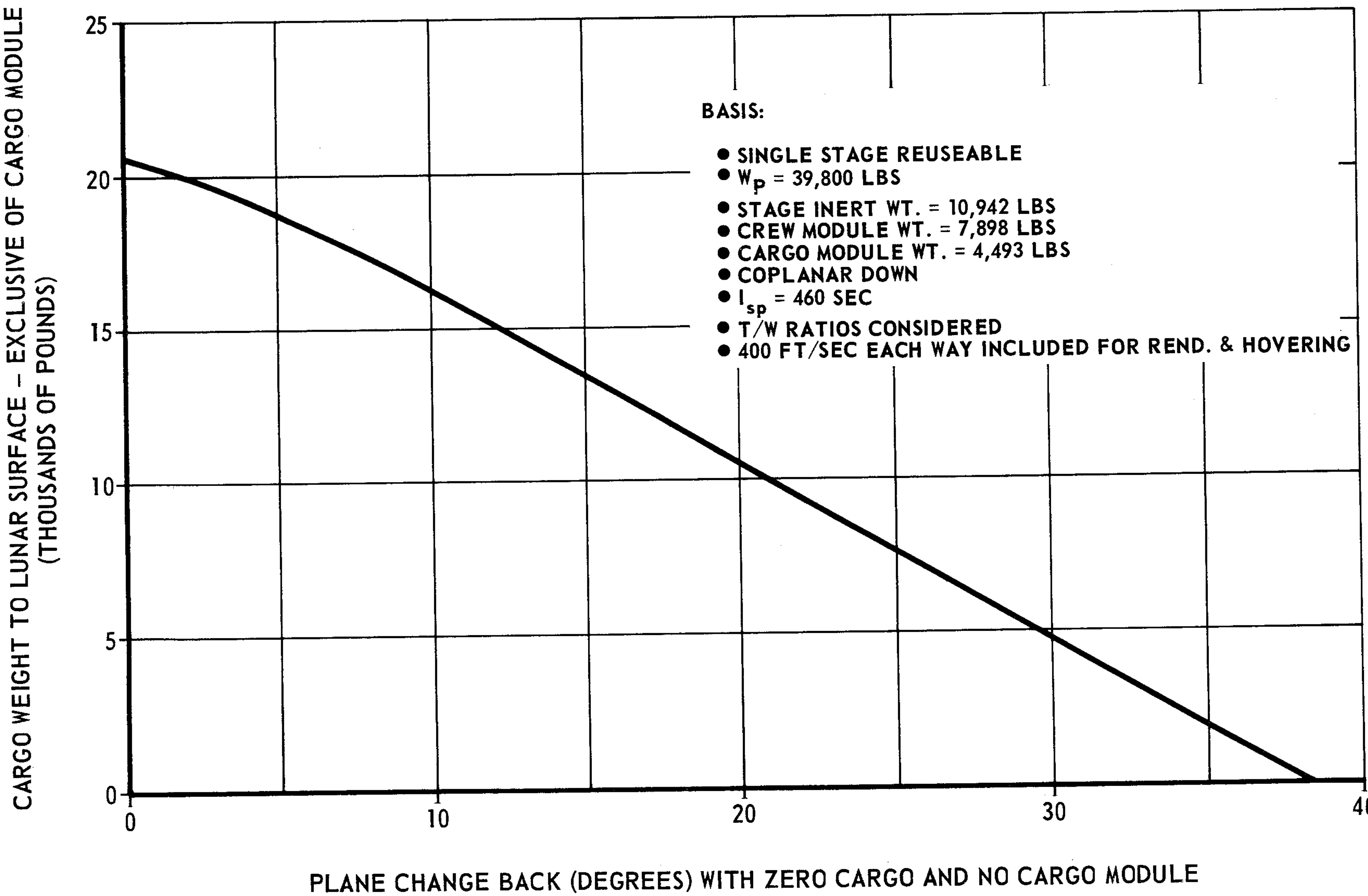


Figure 1.4.2.0-4. LUNAR ABORT CAPABILITY VS. CARGO WEIGHT DOWN

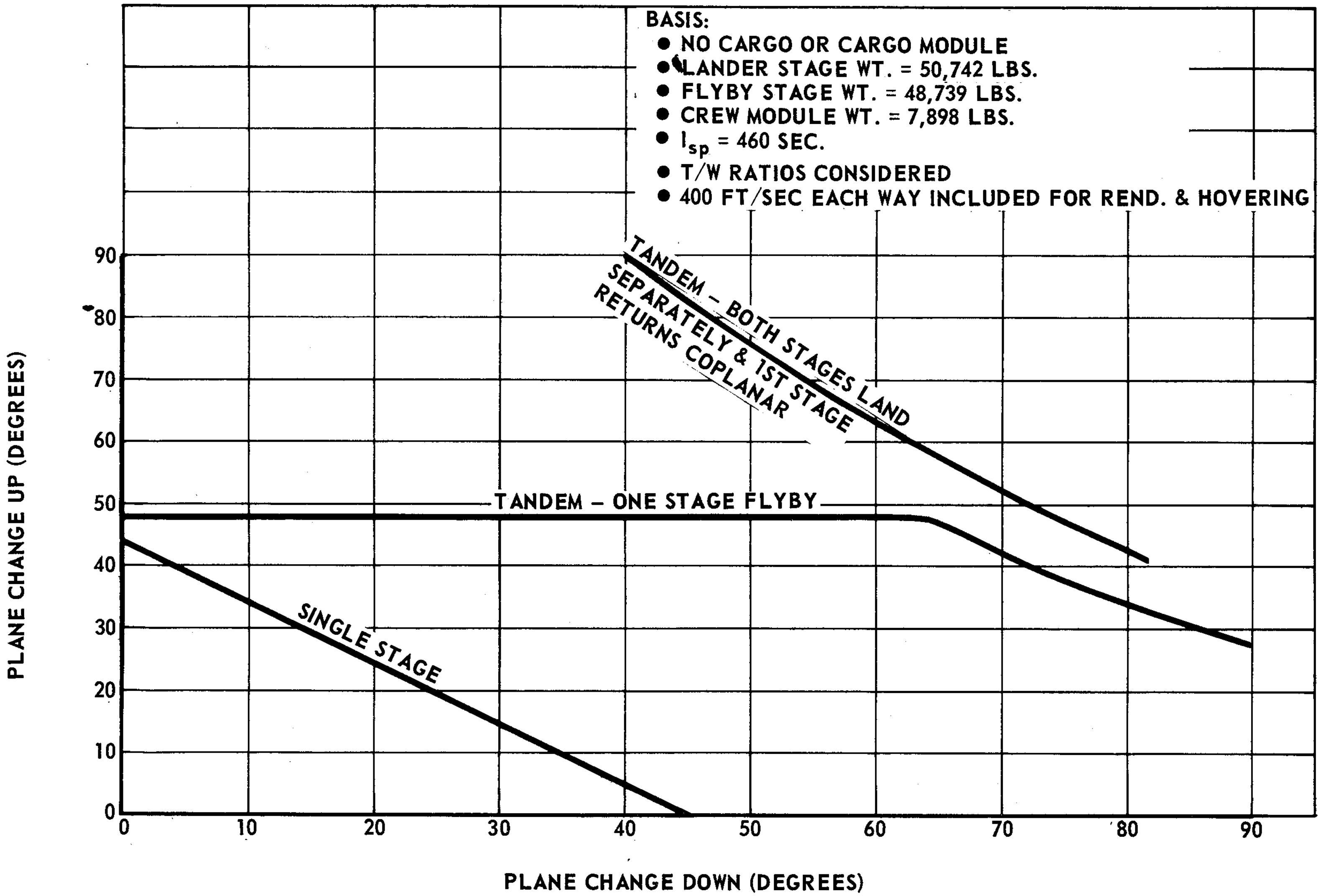


Figure 1.4.2.0-5. RESCUE CAPABILITIES TO LUNAR EQUATOR

1.4.3.1 (Continued

b. The astrionics module as configured to act in the dual capacity of directing the Saturn V during its powered flight (weight = 2621 pounds).

c. A shroud for mounting and protecting the Space Tug during the Saturn V portion of the flight.

The crew module and other Tug elements may be transported as payload for these missions. If so, the crew module may be manned.

Representative configurations for performance of these missions are shown in Figure 1.4.3.1-1.

As shown in Figure 1.4.3.1-2, the payload capability of the four stage Saturn V is relatively insensitive to the Space Tug propulsion module size. An optimumly sized propulsion module weighing 80,000 pounds plus its astrionics module will deliver a payload of 83,000 pounds to lunar polar orbit. The baseline propulsion module with a gross weight of 45,696 pounds (39,800 pounds of propellant) can deliver 76,400 pounds of payload or 6600 pounds less than optimum. Utilization of more than one Tug propulsion module does not improve capability.

1.4.3.2 Utilization of the Space Tug with Nuclear Shuttle

A primary role envisioned for the Nuclear Shuttle is to carry payloads between earth orbit and lunar orbit. For these missions, the Space Tug lunar landing elements will be the principal payload. Because of this mutual mission role, the Space Tug is expected to provide the astrionics for the Nuclear Shuttle flight and the life support functions for the passengers and crew.

For this role, therefore, the <u>active</u> Space Tug elements to be used are:

a. The astrionics module as configured in the dual capacity for a lunar landing mode and to direct the Nuclear Shuttle flight.

b. The crew module configured for the 3 man/50 day lunar mission.

1.4.3.3 Earth Orbit to Lunar Orbit Transfer and Return Using Tug Elements

Space Tug propulsion modules may also be assembled to provide a chemical translunar shuttle to (1) transfer mission components from earth orbit to lunar orbit for a subsequent lunar landing mission, and (2) to return these components to earth orbit after mission completion.

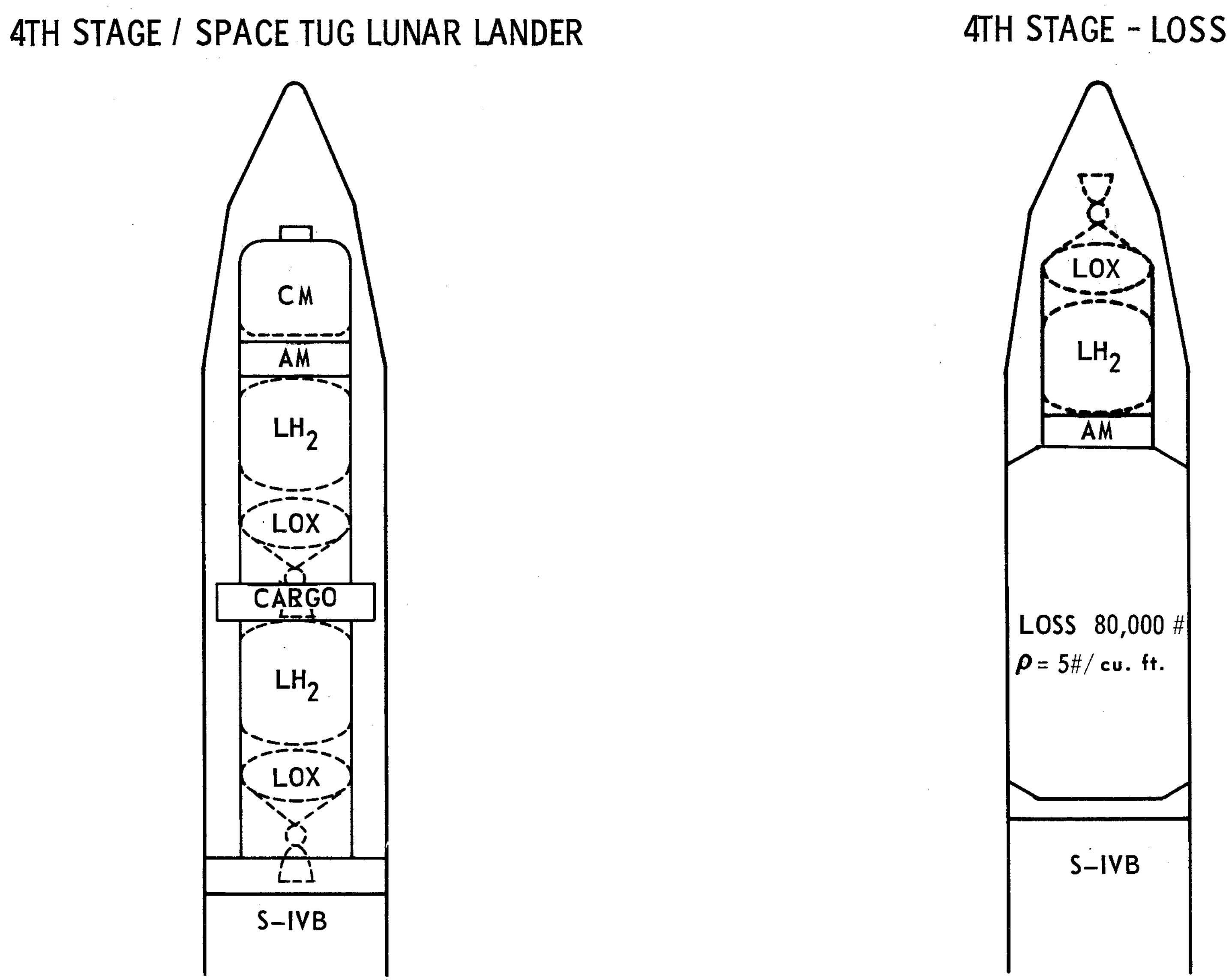


Figure 1.4.3.1-1. CONFIGURATIONS FOR SATURN VC TRANSLUNAR

1.4.2 (Continued)

vehicle capability for this method is shown on the upper curve of the figure. As an example, the figure shows the vehicle can make an immediate round trip with a plane change down and back of approximately 62°. With a 90° plane change down the allowable plane change up is approximately 30°, which means a waiting time on the surface of approximately 4-1/2 days $\left(\frac{90^\circ - 30^\circ}{13^\circ/\text{day}}\right)$ before the Tug can return to the LOSS.

Under certain minimal plane change conditions, a single stage vehicle can perform the rescue mission. For example, Figure 1.4.2.0-5 shows a single stage can perform a 22° plane change both ways without waiting on the surface. However, if a 30° plane change down is required, the Tug must wait until the landing site is within 15° of the LOSS orbit before it can return (10 days or 1 day). If more than a 45° plane change down is required, the single stage configuration cannot perform the mission. Figure 1.4.2.0-6 shows the rescue capabilities of the configurations and related mission modes reference to the longitude and latitudes of the lunar surface.

1.4.3 Translunar Missions

Three modes for utilization of the Space Tug for transfer to lunar orbit were considered, i.e.:

a. Utilization of the Space Tug primary propulsion module as an upper stage for the Saturn V.

b. Utilization of the Space Tug with the Nuclear Shuttle.

c. Space based primary propulsion modules for transfer between low earth orbit and lunar orbit.

1.4.3.1 Saturn V Fourth Stage

The Space Tug primary propulsion module will be used as an upper (fourth) stage to the three-stage Saturn V vehicle for:

a. Placement of the Lunar Orbiting Space Station (LOSS).

b. Placement of other lunar landing components in lunar orbit.

For these missions the primary Space Tug elements to be used will be:

a. The primary propulsion module (propellant capacity = 39,800 pounds) as designed for lunar missions.

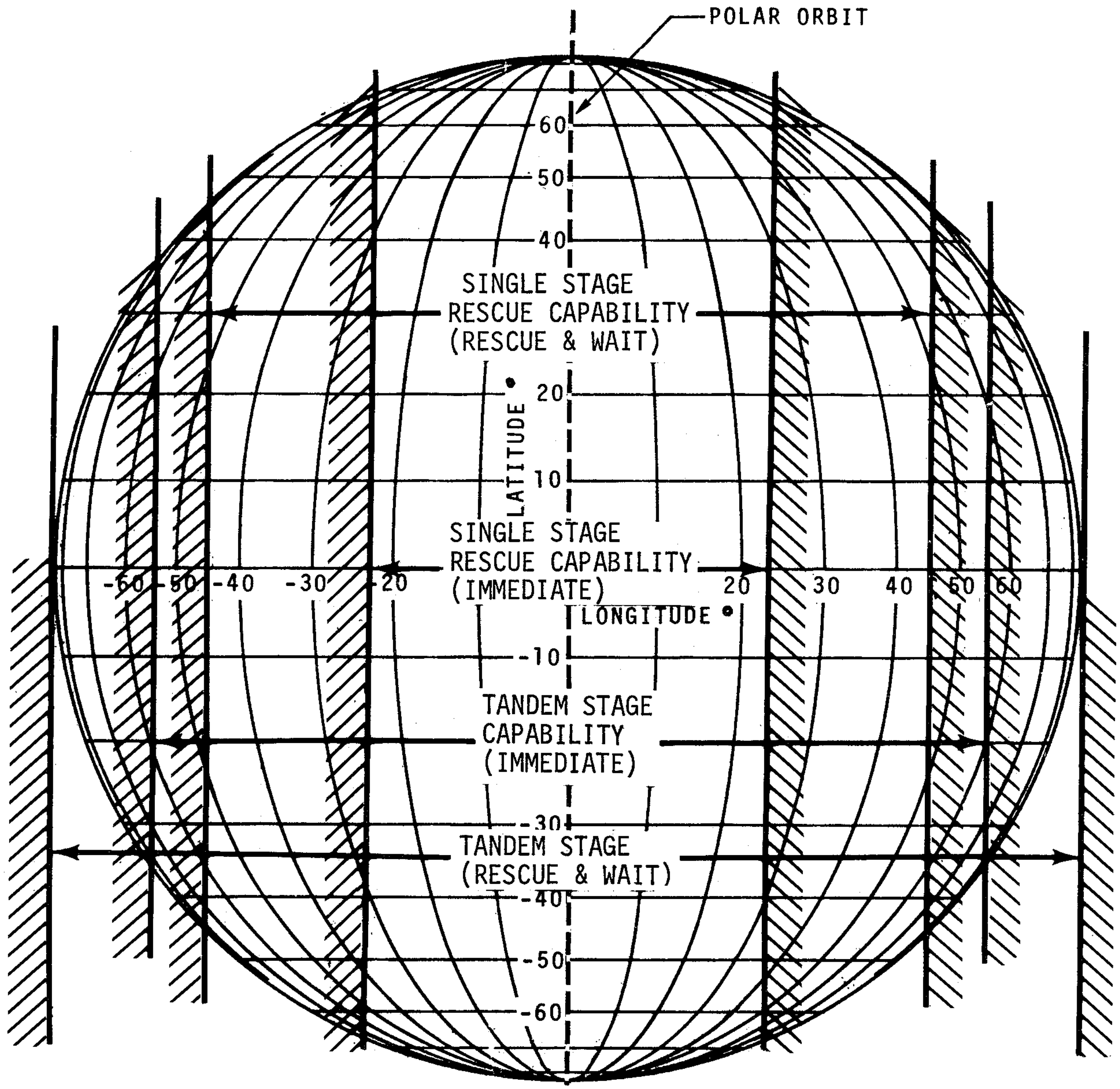


Figure 1.4.2.0-6. SPACE TUG RESCUE CAPABILITY FROM LUNAR SURFACE

4TH STAGE WEIGHT (LBS) (I_{sp} = 460 SEC.)	**PAYLOAD IN LUNAR ORBIT (LBS)**	
	J–2 ENGINES THRUST = 202K LBS I_{sp} = 427.9 SEC MR = 5.0:1	IMPROVED J–2 ENGINES THRUST = 202 K LBS I_{sp} = 439.4 SEC MR = 5.0:1
SINGLE STAGE		
45,000	76,400	81,800
80,000 (MAXIMUM PERFORMANCE)	83,000	–
70,000 (MAXIMUM PERFORMANCE)	–	87,000
DUAL STAGES (FIRST STAGE EXPENDABLE)		
60,000/40,000	76,000	–
49,000/35,000	–	80,000

CONCLUSIONS

- NO ADVANTAGE TO DUAL TWO STAGE 4TH STAGE
- SLIGHT ADVANTAGE LARGE SINGLE STAGE 4TH STAGE
- 45,000 LB SPACE SHUTTLE COMPATIBLE STAGE, ADEQUATE

Figure 1.4.3.1-2. SATURN V - 4TH STAGE

1.4.3.3 (Continued)

The total weight of the fueled Space Tug components and other mission components for the manned lunar landing mission is approximately 70,000 pounds in lunar orbit. This weight represents the required payload from earth orbit to lunar orbit for the translunar mission. After completion of the lunar landing mission and return from the lunar surface to lunar orbit, the mission components with 10,000 pounds of return payload will weigh approximately 30,000 pounds. This weight represents the overall return payload to earth orbit from lunar orbit.

The following Space Tug components can be utilized to assemble configurations for accomplishment of the translunar mission:

a. Primary propulsion modules (propellant capacity of 39,800 pounds each) outfitted for the lunar mission.

b. Astrionics modules designed for the translunar mission with the clustered propulsion modules

c. Staging and module clustering hardware

Figure 1.4.3.3-1 shows the relative weight of various configuration alternatives for delivering these required payloads (70K pounds out and 30K pounds back). This figure also shows the weights of these configurations compared to those capable of transferring 120,000 pounds to lunar orbit and returning 20,000 pounds to earth orbit (nominal specified Nuclear Shuttle payload). Figure 1.4.3.3-2 shows some possible arrangements for the various configuration alternatives exclusive of the reuseable single stage for the 70,000/30,000 pound payload transfer. The reuseable single stage was omitted because of its excessive size, i.e.: a cluster of 36 propulsion modules.

1.4.4 Interplanetary Missions

Two modes for utilization of the Space Tug for providing injection velocity for interplanetary missions were considered, i.e.:

a. A primary propulsion module as an upper stage for the Saturn V vehicle.

b. Primary propulsion modules for injection out of low earth orbit.

Although the primary propulsion module and/or the secondary propulsion module may have other applications for interplanetary missions such as providing the braking velocity for planetary orbiter and landing missions,

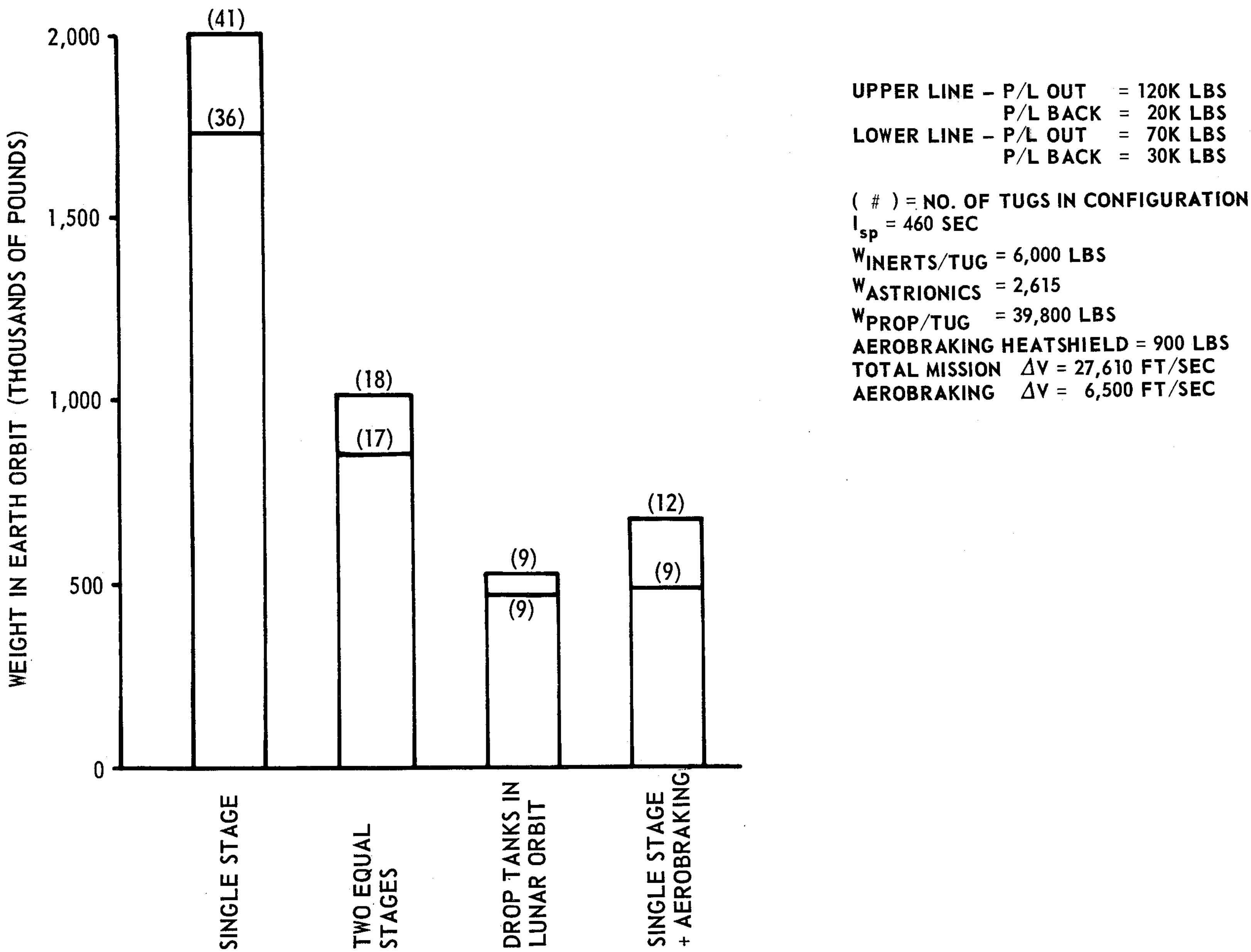


Figure 1.4.3.3-1. LUNAR MISSION PERFORMED WITH TUGS

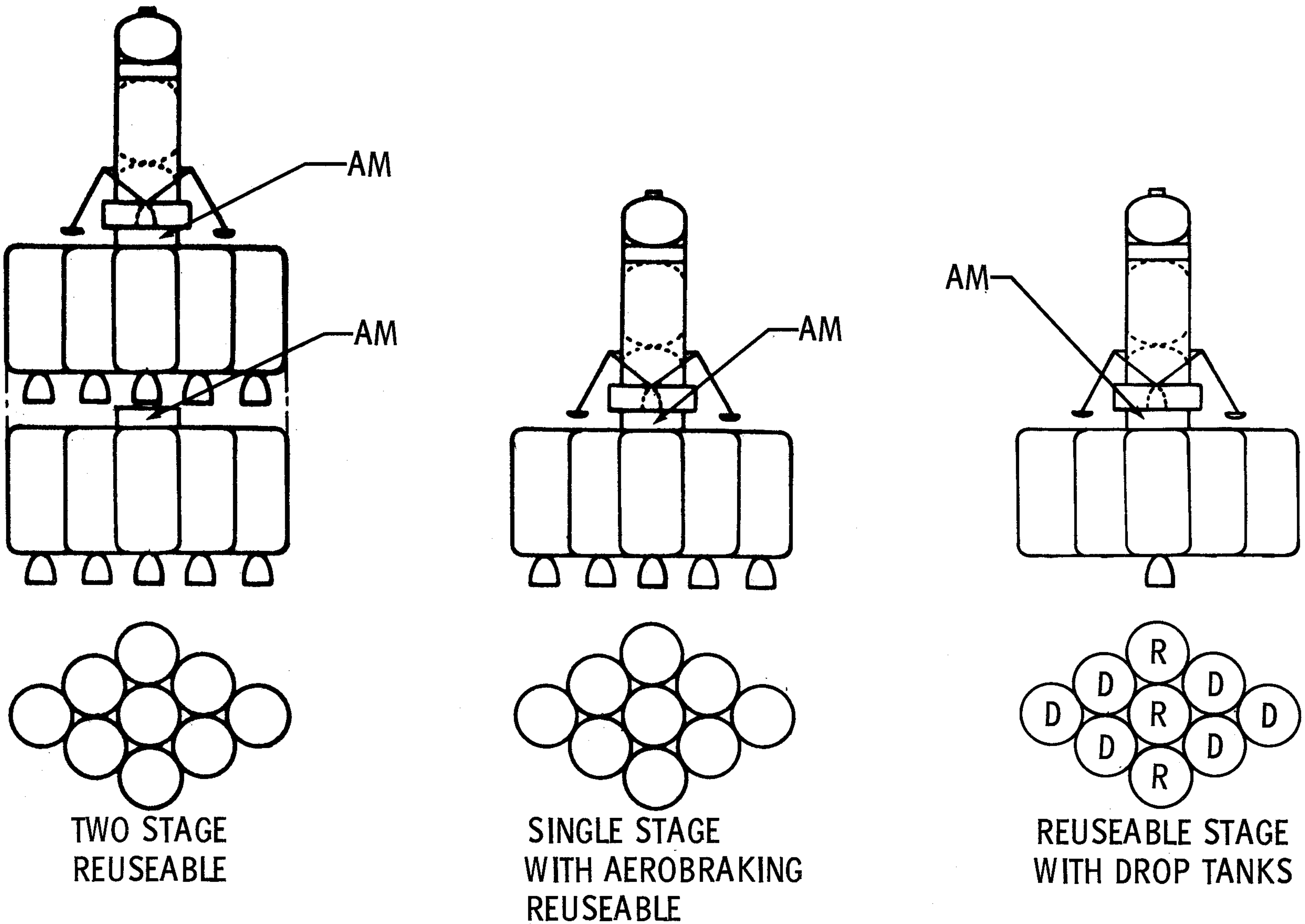


Figure 1.4.3.3-2. CHEMICAL TRANSLUNAR CONFIGURATION ALTERNATIVES

1.4.4 (Continued)

and for providing the necessary propulsion for landing on the various planets or asteroids, these missions were not investigated as part of this study activity. Such applications should be investigated in follow-on activities.

1.4.4.1 Saturn V Upper Stage

The Space Tug primary propulsion module can be used as an upper stage on the three stage Saturn V vehicle to provide injection and velocity to spacecrafts for interplanetary missions. For these missions the Space Tug elements will be:

a. The primary propulsion module (propellant capacity of 39,800 pounds) as designed for reuse for synchronous orbit missions, but stripped for use in an expendable mode.

b. The astrionics module configured to provide the necessary intelligence for directing the Tug portion of the mission and also for directing the Saturn V during its powered flight.

c. A shroud for mounting and protecting the Space Tug during the Saturn V portion of the flight.

The selected configuration for accomplishing these missions is a single primary propulsion module (propellant capacity of 39,800 pounds) used in an expendable mode. For the various missions considered and shown on Figure 1.4.4.1-1, this size stage will deliver payloads within 1,000 pounds of those that could be delivered by optimumly sized stages. Figure 1.4.4.1-1 shows the performance of this selected configuration to accomplish various interplanetary missions as a fourth stage on either a standard Saturn V vehicle or a Saturn V vehicle employing improved J-2 engines for the S-II and S-IVB stages.

As shown on Figure 1.4.4.1-2, little improvement in payload capability is gained when two Tug stages are used with the Saturn V.

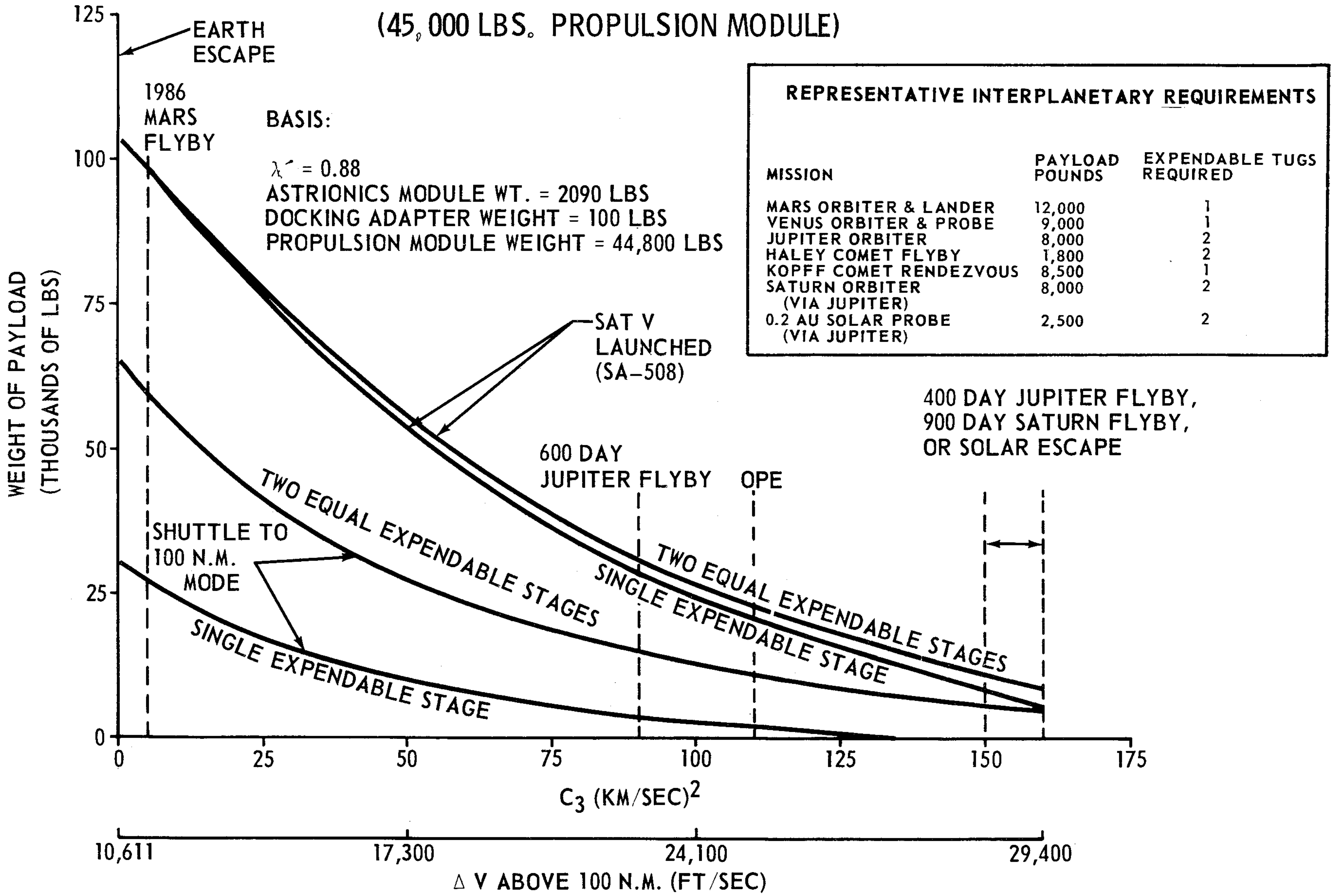
1.4.4.2 Injection from Low Earth Orbit for Interplanetary Missions

Space Tug propulsion modules may be utilized to provide the injection velocity for interplanetary missions departing from low earth orbit for mission origin. For these missions the available Tug elements for assembly into various configurations will be:

MISSION	PAYLOAD (POUNDS)	
	J-2 ENGINES ON S-II & S-IVB STAGES OF SATURN V	IMPROVED J-2 ENGINES ON S-II & S-IVB STAGES OF SATURN V
EARTH ESCAPE	107,000 (107,500)*	113,500 (113,500)
MARS FLYBY (1971 & 1986)	99,500 (100,000)	105,000 (105,000)
MARS FLYBY (1976)	82,000 (82,000)	88,000 (88,000)
JUPITER FLYBY (600-DAY TRIP)	32,500 (33,500)	35,500 (36,000)
OPE FLYBY (9-YEAR TRIP - 1977)	25,500 (26,500)	28,000 (28,500)
JUPITER FLYBY (400-DAY TRIP), SATURN FLYBY (900-DAY TRIP), & SOLAR SYSTEM ESCAPE	13,000 (13,500)	15,000 (15,000)

* NOTE: NUMBERS IN PARENTHESIS ARE PAYLOADS FOR OPTIMUM SIZE STAGES

Figure 1.4.4.1-1. SATURN VC SPACE TUG INTERPLANETARY CAPABILITY



MISSION	PAYLOAD POUNDS	EXPENDABLE TUGS REQUIRED
MARS ORBITER & LANDER	12,000	1
VENUS ORBITER & PROBE	9,000	1
JUPITER ORBITER	8,000	2
HALEY COMET FLYBY	1,800	2
KOPFF COMET RENDEZVOUS	8,500	1
SATURN ORBITER (VIA JUPITER)	8,000	2
0.2 AU SOLAR PROBE (VIA JUPITER)	2,500	2

Figure 1.4.4.1-2. INTERPLANETARY PERFORMANCE

1.4.4.2 (Continued)

a. The primary propulsion module as designed for the earth orbit missions but with the shielding removed for utilization in an expendable mode.

b. The same primary propulsion module as designed for the earth orbit missions for utilization in a reuseable mode.

c. The astrionics module configured for the expendable interplanetary orbit mission stage (weight approximately equal to 2090 pounds).

d. The astrionics module configured for the reuseable interplanetary orbit mission lower stage (weight equal 2417 pounds).

The interplanetary missions were not used to size the specific Space Tug elements. The selected Space Tug elements were only considered as to their adaptability to accomplish the planetary missions. Various potential configurations are shown in Figure 1.4.4.2-1. The representative configuration will be dependent on the specific interplanetary mission requirements and may consist of either a single stage expendable module, a two stage system with an expendable module in each stage, or a two stage system consisting of an expendable upper stage with a reuseable lower stage. Figure 1.4.4.1-2 shows the applicability of one and two stage expendable Space Tug systems for accomplishment of a range of different interplanetary missions. It also shows that the majority of the interplanetary missions can be accomplished using various Tug configurations launched from low earth orbit.

1.5 RESOURCES

The Space Tug vehicle configurations will not require any unique technology or special facilities for their design, development and fabrication. The Space Tug can be operational 6-1/2 years from the start of the Phase D activity to the completion of the second flight test in the flight test program. This estimate is conservative and may be reduced by approximately 1/2 to 1 year by overlapping the development, test and acquisition activities. Figure 1.5.0.0-1 illustrates the master program schedule.

As the basic designs of the propulsion and astrionics module concepts are similar to those employed on the Saturn V vehicle and other current space program vehicle configurations, the design requirements, the types of tests, test facilities and equipment requirements are known and available. The manufacturing procedures and equipment currently used are applicable to the Space Tug. For this analysis it was assumed that the design facilities of the current space program contractor's companies would be available for this program. Similarly, the test facilities presently owned by NASA could be used to conduct many of the tests required for these Space Tug components, modules and kits. Only a minimal amount of facilities modi-

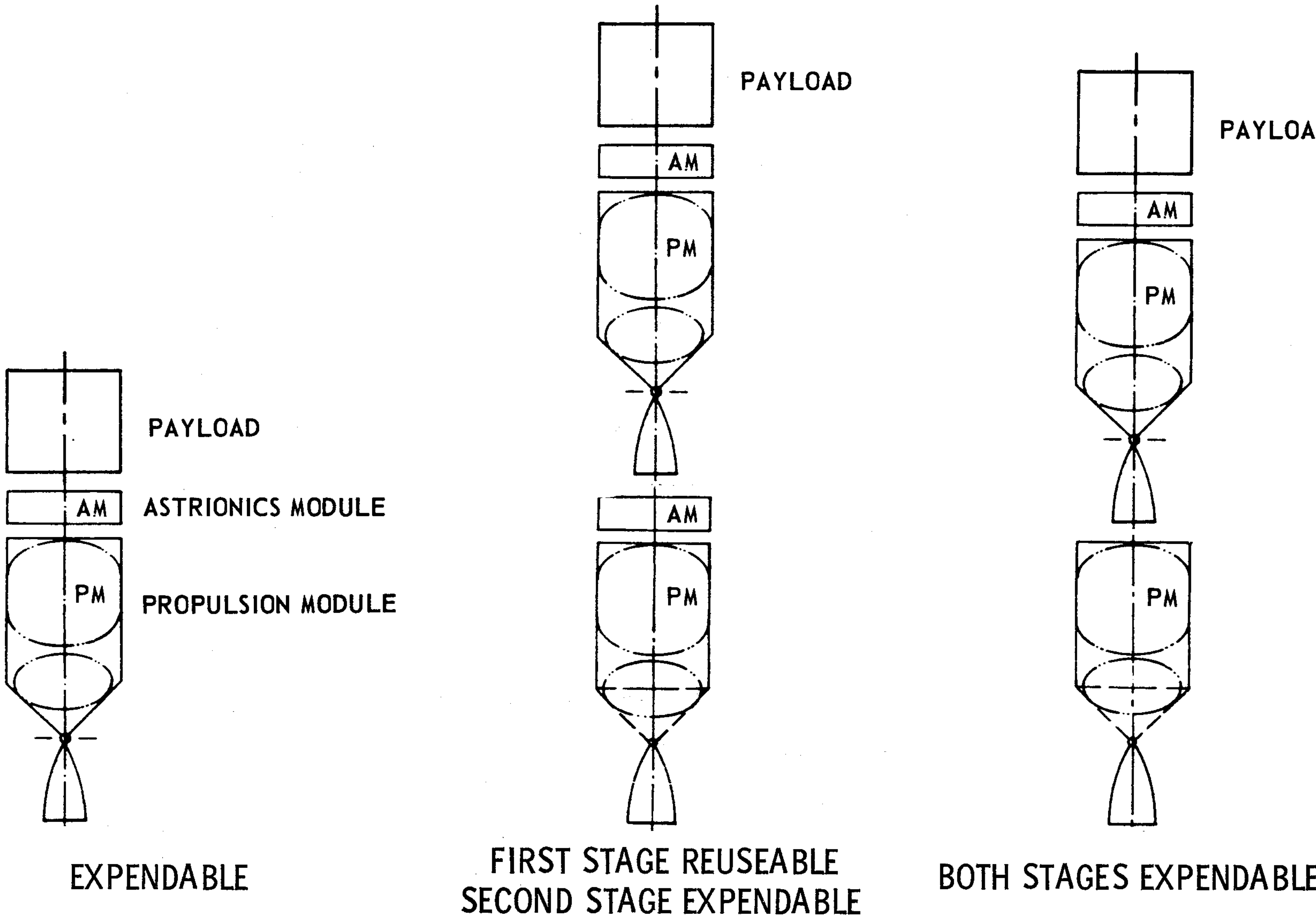
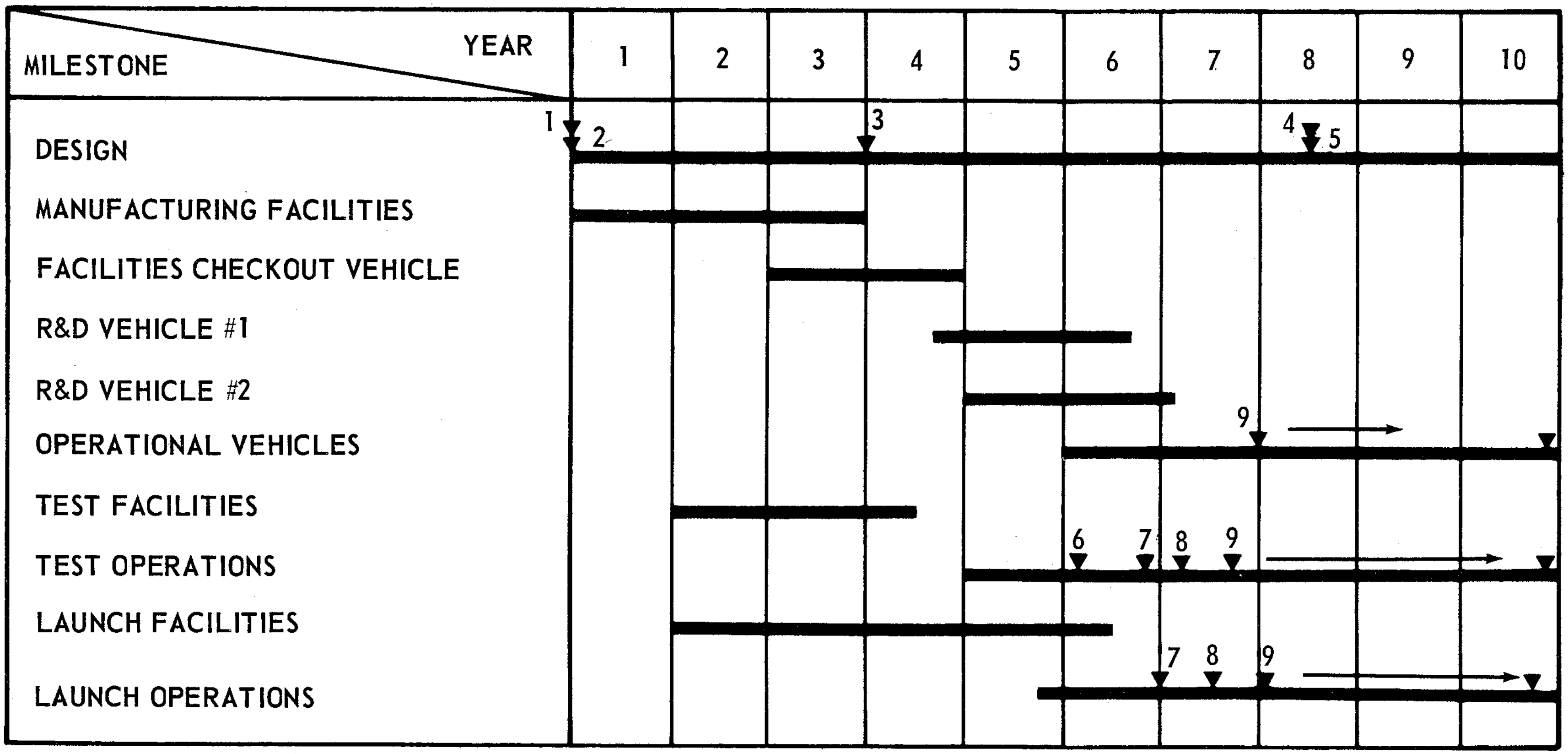


Figure 1.4.4.2-1. CONFIGURATIONS FOR INTERPLANETARY MISSIONS OUT OF LOW EARTH ORBIT



1. AUTHORIZATION TO PROCEED (PHASE D)
2. TOP DRAWING RELEASE
3. INITIAL DRAWING RELEASE
4. FINAL DRAWING RELEASE
5. SUSTAINING ENGINEERING
6. FACILITIES C/O VEHICLE
7. R&D VEHICLE #1
8. R&D VEHICLE #2
9. OPERATIONAL VEHICLES

Figure 1.5.0.0-1. MASTER PROGRAM SCHEDULE fications would be required to compensate for the smaller weights, diameters and lengths involved. In the manufacturing of the components which comprise the Space Tug, it was assumed that the NASA Michoud facility could be utilized to fabricate the propulsion, crew, and cargo modules, the landing legs, and the docking adapter. Utilizing the existing manufacturing facilities at a production rate of 6 Space Tugs per year requires between 10 and 15% of the available manufacturing facility at Michoud.

As the materials of construction for the Space Tug vehicle components are similar to those presently utilized, a limited manufacturing development program is required. This manufacturing development effort would be directed toward development test activity for methods and procedures for applying and handling the superinsulation and the Hexcel/Aluminum micrometeoroid shield.

As the astrionics module is in many ways similar to the existing instrument unit of the Saturn V program, it was assumed that the existing instrument unit facilities could be utilized to fabricate the astrionics module for the Space Tug program. No major new items of capital equipment, tooling, or facilities, are anticipated.

Transportation of the assembled modules to the launch site present a lesser problem than many of today's space vehicles as the sizes will not impose any restriction on the method of transportation used. The restrictive limitations of 15 foot diameter and 60 foot length coupled with the lightweight of the modules (maximum weight of any module is less than 10,000 pounds) makes it possible to deliver components to the launch facility by various modes, such as rail, truck, sea or air.

In assessing the impact of the Space Tug on the launch facility, it was assumed that the Space Tug would be launched from Cape Kennedy utilizing the EOS. As a result, the impact of the Space Tug on the launch facility is slight. The major new facilities include: (1) New receiving and inspection buildings; (2) some additional handling and transportation equipment; (3) modifications to the VAB for Space Tug assembly operations; (4) handling equipment at the launch pad for installing of the Space Tug within the Space Shuttle cargo bay; (5) operational and maintenance facilities; (6) refurbishment facilities; and (7) other support buildings and facilities.

Time from the receipt of the Space Tug components at the launch facility to the launch of the Space Tug in the cargo bay of the Space Shuttle could be as low as nine weeks. This includes receiving and inspection of the modules, assembly operations as well as all inspection and checkout operations prior to launch.

1.6 COSTS

This paragraph summarizes the detail cost data presented in Volume II of this report. Trends in costs associated with configuration alternatives and with variations in performance and operational variables are presented in Section 3 "Operational Econometrics". Figure 1.6.0.0-1 illustrates the cost study logic.

Cost data were developed for (1) the Space Tug modules, kits, and components, (2) vehicle configurations which can be assembled from these elements, (3) an overall program with a representative mission model, and (4) cost sensitivity to size performance and operational variables.

The cost methodology used to define costs are shown in Figure 1.6.0.0-2. The costs were categorized into two nonrecurring cost groups and two recurring cost groups, i.e.:

a. Nonrecurring Costs

   1. Design and Development Costs - "A" Costs
   2. Test Costs - "B" Costs

b. Recurring Costs

   3. Investment Costs - "C" Costs
   4. Operational Costs - "D" Costs

The nonrecurring Design and Development Costs include (1) the cost of design, and (2) the cost of acquisition and activation of the manufacturing, test, and operational facilities. The Test Costs include all the costs associated with the developmental testing of components, kits, modules, as well as the overall Space Tug vehicle configurations. The Investment Costs are the recurring costs associated with the production program including all components, kits, modules, spares, sustaining engineering, etc. The impact of a learning curve on the number of production units is included in development of the investment costs. The Operational Costs are those costs associated with the operation of the Space Tug to accomplish a mission traffic model. Included in this series of costs are the vehicle refurbishment cost, propellant delivery cost, launch and recovery cost, engineering support and program integration costs.

In the development of the costs, available cost estimating relationships (CER's) from The Boeing Company, Aerospace Corporation, and other space program contractors were used wherever applicable. In addition, estimates were made using historical cost data and cost data developed in other space program studies. In other instances, cost data was provided directly by the NASA and other space program contractors reports. These include the cost data

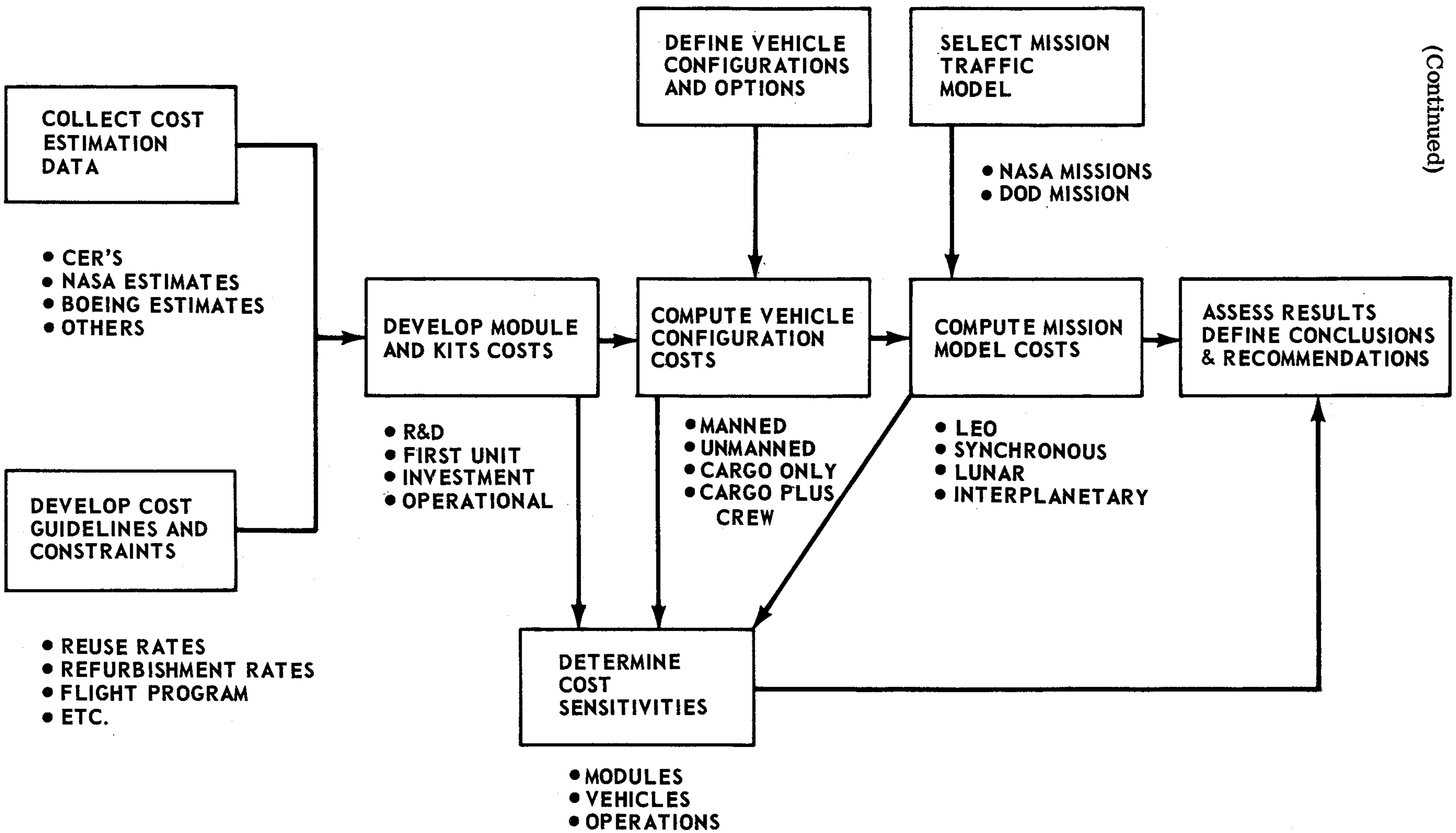


Figure 1.6.0.0-1. COST ANALYSES LOGIC

SPACE TUG TOTAL VEHICLE COST

DESIGN AND DEVELOPMENT COST "A" COSTS

- Modules
  - Crew
  - Cargo
  - Astrionics
  - Propulsion
- Kits
  - Landing Legs
  - Manipulator Arms
  - Auxiliary Power Kit
  - Drop Tanks
- Others
  - Manufacturing Development
  - Assembly
  - Facility
  - Tooling
  - GSE

TEST COSTS "B" COSTS

- Modules
  - Crew
  - Cargo
  - Astrionics
  - Propulsion
- Kits
  - Landing Legs
  - Manipulator Arms
  - Auxiliary Power Kit
  - Drop Tanks
- Others
  - Flight Tests
  - Facility Checkout
  - SDF
  - Ground Test
  - Test Hardware
  - Test Facilities

INVESTMENT COSTS "C" COSTS

- Module Production
- Kits Production
- R&D Modifications
  - 2 Flight Tests
  - 1 Facility C/O
- Initial Spares
- Sustaining Tooling

OPERATIONAL COST "D" COSTS

- Refurbishment
- Spares
- Maintenance of Facility
- Engineering Support
- Program Integration
- Launch
- Recovery

SE&I @ 5% And Program Management @8% Should Be Added to Obtain Total Program Costs

Figure 1.6.0.0-2. REPRESENTATIVE SPACE TUG TOTAL VEHICLE COSTS

1.6 (Continued)

received from the NASA/MSFC on the uprated RL-10 engine, the astrionics module cost provided by IBM Corporation, and the manipulator arms cost data provided by the Matrix Research Corporation. As the costs developed, are based on historical CER's and/or current NASA/DOD design, test and operational philosophies, they may not be entirely applicable to the future philosophies of the Space Tug and other Space Transportation Systems.

The resulting cost data were normalized and compared as applicable to cost data developed by the Aerospace Corporation for the unmanned Orbit-to-Orbit Shuttle. These comparisons, which showed reasonable agreement are presented in Volume II.

1.6.1 Cost Considerations and Results

Figure 1.6.1.0-1 shows the Design and Development Costs ("A" costs) for all of the modules, kits and components used in this study. These costs, when combined with the Test Costs ("B" costs) shown in Figure 1.6.1.0-2 identify the total non-recurring costs for any vehicle configuration and its supporting facilities. These nonrecurring costs were developed using the current NASA test and manufacturing philosophies. Two R&D flight test vehicles and one facilities checkout vehicle were considered a part of the test program. These vehicles were then refurbished and their components were made available for the operational program. The manufacturing facilities were sized for a six per year production rate. The launch facilities (peculiar to the Space Tug) were defined for a ten per year launch rate.

The Investment Cost ("C" costs) is based on the number of vehicles, initial spares, sustaining tooling, SE&I and program management necessary to accomplish a specific mission traffic model. A major portion of the Investment Costs will be provisioning of the vehicle fleet, i.e., modules and kits with their spares requirements. The recurring Investment Costs were developed on the basis of refurbishment of the two R&D test vehicles and the facility checkout vehicle for incorporation into the operational program. For the costing study, the first production vehicle for first unit costs was considered to be the first one made after the production of the three vehicles used in the R&D program. A learning curve of 90% was used to determine the production cost of subsequent articles. The first unit costs of these items are shown in Figure 1.6.1.0-3.

The Operational Costs ("D" Costs) are dependent on the mission traffic model, the configurations required, program duration, the launch rates, etc. Further Operational Costs are also strongly influenced by the assumptions discussed

1.6.1 (Continued)

20K PROPULSION MODULE – 170.46
45K PROPULSION MODULE – 202.57
68K PROPULSION MODULE – 223.96

20K DROP TANKS – 31.65
45K DROP TANKS – 39.31
68K DROP TANKS – 43.75

ASTRIONICS MODULE EXPENDABLE – 31.55
ASTRIONICS MODULE LOWER SYN – 34.55
ASTRIONICS MODULE UPPER SYN – 36.15
ASTRIONICS MODULE LUNAR – 38.80

CREW MODULE – 130.91

CARGO MODULE – ROUND – 9.02
CARGO MODULE – DOUGHNUT – 20.52

MANIPULATOR ARMS – 6.16
DOCKING ADAPTER – 6.16
LANDING LEGS – 11.50
AUXILIARY POWER KIT – 0.26
STAGING ADAPTER – 17.20

Figure 1.6.1.0-1. DESIGN & DEVELOPMENT "A" COST SUMMARY (DOLLARS IN MILLIONS)

- 20K PROPULSION MODULE – 162.76
- 45K PROPULSION MODULE – 181.22
- 68K PROPULSION MODULE – 197.17

- 20K DROP TANK – 30.03
- 45K DROP TANK – 44.88
- 68K DROP TANK – 56.87

- ASTRIONICS MODULE – EXPENDABLE – 50.00
- ASTRIONICS MODULE – LOWER SYN – 53.40
- ASTRIONICS MODULE – UPPER SYN – 55.32
- ASTRIONICS MODULE – LUNAR – 60.77

- CREW MODULE – 224.27

- CARGO MODULE – ROUND – 8.86
- CARGO MODULE – DOUGHNUT – 12.22

MANIPULATOR ARMS	9.40
DOCKING ADAPTER	9.40
LANDING LEGS	12.72
AUXILIARY POWER KIT	0.71
STAGING ADAPTER	11.50

Figure 1.6.1.0-2. TEST "B" COST SUMMARY (DOLLARS IN MILLIONS)

- 20K PROPULSION MODULE – 5.10
- 45K PROPULSION MODULE – 5.91
- 68K PROPULSION MODULE – 6.24
- 20K DROP TANK – 2.04
- 45K DROP TANK – 2.77
- 68K DROP TANK – 3.13

- ASTRIONICS MODULE–EXPENDABLE – 7.77
- ASTRIONICS MODULE–LOWER SYN – 9.82
- ASTRIONICS MODULE–UPPER SYN – 10.26
- ASTRIONICS MODULE–LUNAR – 13.48
- CREW MODULE – 3 MEN 50 DAYS – 33.90
- CREW MODULE – 15 MEN, 2 DAYS – 30.09
- CARGO MODULE – ROUND – 3.00
- CARGO MODULE – DOUGHNUT – 3.40

- MANIPULATOR ARMS – 0.30
- DOCKING ADAPTER – 0.30
- LANDING LEGS – 5.50
- AUXILIARY POWER KIT – 0.12
- STAGING ADAPTER – 0.36

Figure 1.6.1.0-3. FIRST UNIT COST SUMMARY (DOLLARS IN MILLIONS)

1.6.1 (Continued)

below:

Reuse - To develop costs, it was necessary to assume the average number of reuses for each of the Space Tug modules and kits. Using a very limited historical data base, plus consideration of component complexity, mission duration and mission complexity, reuse rates, as shown on Figure 1.6.1.0-4, were established. The reuse rates for the various Space Tug modules are as shown, dependent on the complexity of the mission to which the modules will be applied. For example, 50 reuses of the propulsion module were assumed for low earth orbit missions. For lunar landing missions, ten reuses per module were assumed because of the more complex, longer duration requirements.

It was also assumed that the vehicle elements could be refurbished after the basic mission for adaptation to expendable missions.

Refurbishment - A refurbishment cost of three percent of first unit cost was used. This value (based on data developed for the NASA by Boeing under an Econometrics Study, Contract NAS8-30522) assumed a ground based refurbishment and was based on a "desirable" target rather than historical actuals. (The limited data on the X-20 research vehicle showed 10 to 20 percent refurbishment costs.) It was assumed that continuing experience with relatively fixed configurations could, however, reduce refurbishment cost to this desired three percent.

EOS Operational Costs - The Space Tug operational modes depend on the EOS to deliver to orbit either the fueled Tug or propellant for Tug refueling. For this analysis a round trip EOS cost of 3.5 million dollars per flight was used. This cost results in a fuel delivery cost to orbit of approximately 75 dollars per pound. With this value, the propellant delivery cost represents between 50 percent (LEO) and 80 percent (lunar) of the total mission cost. The EOS mission costs may be as high as six million dollars per flight. If this is true, the Space Tug operational mission costs will be significantly increased.

Specific criteria used to develop the operational costs are shown in Figure 1.6.1.0-5.

The total program costs for a representative mission traffic model are shown in Figure 1.6.1.0-6. The first column identifies the number of missions. The second column identifies the type of mission and the components used in each vehicle configuration. The remaining columns identify the various costs associated with those missions. For the 864 mission program shown, the

MISSION / VEHICLE ELEMENT	LEO BELOW ΔV 8000 FT/SEC	LEO ABOVE ΔV 8000 FT/SEC	SYNCHRONOUS	LUNAR ORBIT	LUNAR LANDING	INTERPLANETARY
PROPULSION MODULE	50	20	20	50	10	1
ASTRIONICS MODULE	50	20	20	50	10	1
CARGO MODULE	100	100	100	100	100	1
CREW MODULE	100	N/A	N/A	50	10	N/A
LANDING LEGS	N/A	N/A	N/A	N/A	10	N/A
DOCKING ADAPTER	100	100	100	100	100	N/A
MANIPULATOR ARMS	100	N/A	N/A	100	100	N/A
DROP TANKS	N/A	N/A	N/A	N/A	N/A	N/A
STAGING ADAPTER AND SEPARATION MECHANISM	N/A	N/A	20	N/A	10	N/A
AUXILIARY POWER KIT	N/A	N/A	N/A	N/A	10	N/A

N/A - NOT APPLICABLE

Figure 1.6.1.0-4. MODULE AND KITS REUSE RATES

COST ELEMENTS	COST	BASIS
PROPELLANT (TO ORBIT COST)	\$75/# - LEO & SYNC \$660/# - LUNAR	NASA/MSFC DATA - 3.5 MILLION DOLLARS PER SHUTTLE LAUNCH TO DELIVER 47,000 LB. PAYLOAD
REFURBISHMENT	3% FIRST UNIT COST	ECONOMETRICS STUDY CONTRACT NAS8-30522
SPACE TUG LAUNCH (ONLY TUG COSTS)	\$3,010,000	COST = \$55,000 $(X)^{.6}$ x 10 X = NUMBER OF LAUNCHES PER YEAR
RECOVERY	\$466,000	COST = \$8,500 $(X)^{.6}$ x 10 X = NUMBER OF LAUNCHES PER YEAR
REFURBISHMENT FACILITY MAINTENANCE	\$5.34 MILLION + 1.8 x GSE COST	COST = .05 (COST OF R&D INVESTMENT FACILITIES, GSE AND SUPPORT EQUIPMENT) X NO. OF YEARS.
SPARES - STRUCTURES AND SUBSYSTEMS	\$75/# x DRY WEIGHT x .03 x 8 x 10	COST = SHUTTLE DELIVERY COST x VEHICLE CONFIGURATION DRY WEIGHT x REFURB. RATE x LAUNCH RATE PER YEAR x NO. OF YEARS
ENGINEERING SUPPORT	\$42,000 x 10 x 50	COST = 50 MEN x 10 YEARS x AVE. MAN YEAR COST
PROGRAM INTEGRATION	\$42,000 x 10 x 50	COST = 50 MEN x 10 YEARS x AVE. MAN YEAR COST

Figure 1.6.1.0-5. OPERATIONAL COST BASIS

(DOLLARS IN MILLIONS)

NO. OF MISSIONS	MISSION DESCRIPTION	DESIGN & DEVELOPMENT COST	TEST COST	INVESTMENT COST	OPERATIONAL COST	SE&I AND PROGRAM MANAGEMENT	TOTAL
200	LEO - UNMANNED 20K PM/AM/CAMR/DA	220.190	234.420	14.923	373.515	113.237	958.285
100	LEO - MANNED - 20K PM/AM/CM/CAMR/MA	137.070	233.870	26.059	280.628	90.803	768.430
42	LEO - MANNED - 20K PM/AM/MA/CM	-0-	-0-	11.675	113.920	16.830	142.425
140	LEO - UNMANNED - 45K PM/AM/CAMR/DA	202.570	181.220	77.435	506.470	129.673	1,097.368
287	SYN - UNMANNED - (2) 45K PM/ (2) AM/DA/SASM	19.800	13.420	386.077	2,019.549	326.804	2,765.650
20	LUNAR - MANNED - 45K PM/AM/CAMD/CM/ LL	-0-	-0-	67.048	1,087.985	154.774	794.653
40	LUNAR - UNMANNED - 45K PM/AM/CAMD/ DA/LL	37.270	32.310	66.412	564.758	93.903	1,309.807
35	INTERPLANETARY - 45K PM/AM	2.000	1.400	184.009	113.911	40.378	341.698
	SUBTOTAL	618.900	696.640	833.638	5,062.736	966.402	
	SE&I AND PROGRAM MANAGEMENT (SPREAD)	82.935	93.350	111.709	678.408		
864	TOTALS	701.835	789.990	945.347	5,741.144		8,178.316

BASIS: $75/LB. LEO AND SYN PROPELLANT DELIVERY COST
$660/LB. LUNAR PROPELLANT DELIVERY COST

LEGEND:
20K PM - 20,000 POUND PROPULSION MODULE
45K PM - 45,000 POUND PROPULSION MODULE
68K PM - 68,000 POUND PROPULSION MODULE
AM - ASTRIONICS MODULE
CM - CREW MODULE
CAMR - CARGO MODULE ROUND
CAMD - CARGO MODULE DOUGHNUT
DA - DOCKING OR PAYLOAD ADAPTER
MA - MANIPULATOR ARM
LL - LANDING LEGS
SASM - STAGING ADAPTER AND SEPARATION MECHANISM

Figure 1.1.0.0-7. REPRESENTATIVE MISSION MODES PROGRAM COST SUMMARY

1.6.1 (Continued)

total program cost would be $8.1B (or $810M per year) for the ten-year program. This cost includes the design, development and test costs and the recurring investment and operational costs. Included in the operations cost is the shuttle operational mission cost of $3.5M per flight. A 5% SE&I and 8% program management cost was charged against each of the missions.

Note that the above costs do not include the cost of the payload, the shuttle development, or the shuttle investment cost. These costs must be added to fully understand the overall program cost.

Utilizing the representative mission model shown in the previous figure, vehicle configurations were identified. For each of the vehicle configurations, the cost of a 50 mission program was developed. From this, the unit cost for the performance of each mission was determined. This unit cost amortizes the R&D costs over the 50 mission program. Figure 1.6.1.0-7 presents a mission unit cost summary. The costs are presented with and without the propellant delivery to orbit costs to (1) show the significant portion of overall cost attributable to propellant delivery, and (2) to allow the user of this data to apply different propellant delivery costs in determining the mission cost. The propellant delivery costs constitute approximately 50-80% of the mission costs and therefore will significantly impact any cost analysis of the Space Tug. Figure 1.6.1.0-8 illustrates the impact of the shuttle mission costs on the mission costs for the Space Tug.

Figure 1.6.1.0-9 shows the effect of reuse rate on mission cost for two representative vehicle configurations, i.e. (1) a single stage configuration with a 68,000 pound propulsion module combined with an astrionics model, and (2) a tandem stage configuration with two 45,000 pound propulsion modules combined with two astrionics modules. For both configurations, the reuse savings levels off before 70 reuses. Further, reuse does not afford measurable savings.

1.6.2 Cost Conclusions and Recommendations

The costing activity for this study was conducted in more detail than that normal for a Pre-Phase A activity. The results have identified the cost drivers and the trends to be expected. The cost for the number of vehicle sizes and configurations, and for the mission model options, plus the cost sensitivity data can be put together in various manners the range of costs attributable to size, performance, operational and programmatic variables.

From the cost analyses and from the resulting cost distributions shown in

MISSION	VEHICLE ELEMENTS	COSTS WITH PROPELLANT DELIVERY	COSTS WITHOUT PROPELLANT DELIVERY
LEO – UNMANNED – CARGO DELIVERY	20 PM, AM, CAMR, DA	$ 2.582	$ 1.153
LEO – MANNED – NO CARGO	20 PM, AM, CM, MA	3.839	2.410
LEO – MANNED WITH CARGO DELIVERY	20 PM, AM, CAMR, CM, MA	3.972	2.543
HIGH LEO – UNMANNED – CARGO DELIVERY	45 PM, AM, CAMR, DA	5.058	1.673
SYNCHRONOUS – UNMANNED	68 PM, AM	7.334	1.550
SYNCHRONOUS – UNMANNED	(2) 45 PM, (2) AM, DA	9.747	2.977
SYNCHRONOUS – UNMANNED	45 PM, 45 DT, AM, DA	10.369	3.599
LUNAR – UNMANNED – CARGO DELIVERY	45 PM, AM, LL, DA	33.255	3.467
LUNAR – MANNED WITH CARGO DELIVERY	45 PM, AM, LL, CAMD, CM, MA	77.934	8.146
INTERPLANETARY – CARGO DELIVERY	45 PM, AM	9.394	6.009

BASIS: UNIT COST IS BASED ON 50 MISSION PROGRAM
$75/# LEO & SYN PROPELLANT DELIVERY COST
$660/# LUNAR PROPELLANT DELIVERY COST

LEGEND

- 20 PM – 20,000 POUND PROPULSION MODULE
- 45 PM – 45,000 POUND PROPULSION MODULE
- 68 PM – 68,000 POUND PROPULSION MODULE
- AM – ASTRIONICS MODULE
- CM – CREW MODULE
- CAMR – CARGO MODULE – ROUND
- CAMD – CARGO MODULE – DOUGHNUT
- DA – DOCKING ADAPTER
- MA – MANIPULATOR ARMS
- 20 DT – 20,000 POUND DROP TANK
- 45 DT – 45,000 POUND DROP TANK
- 68 DT – 68,000 POUND DROP TANK
- LL – LANDING LEGS
- APK – AUXILIARY POWER KIT
- SASM – STAGING ADAPTER PLUS SEPARATION MECHANISM

Figure 1.6.1.0-7. SPACE TUG MISSION COST SUMMARY (DOLLARS IN MILLIONS)

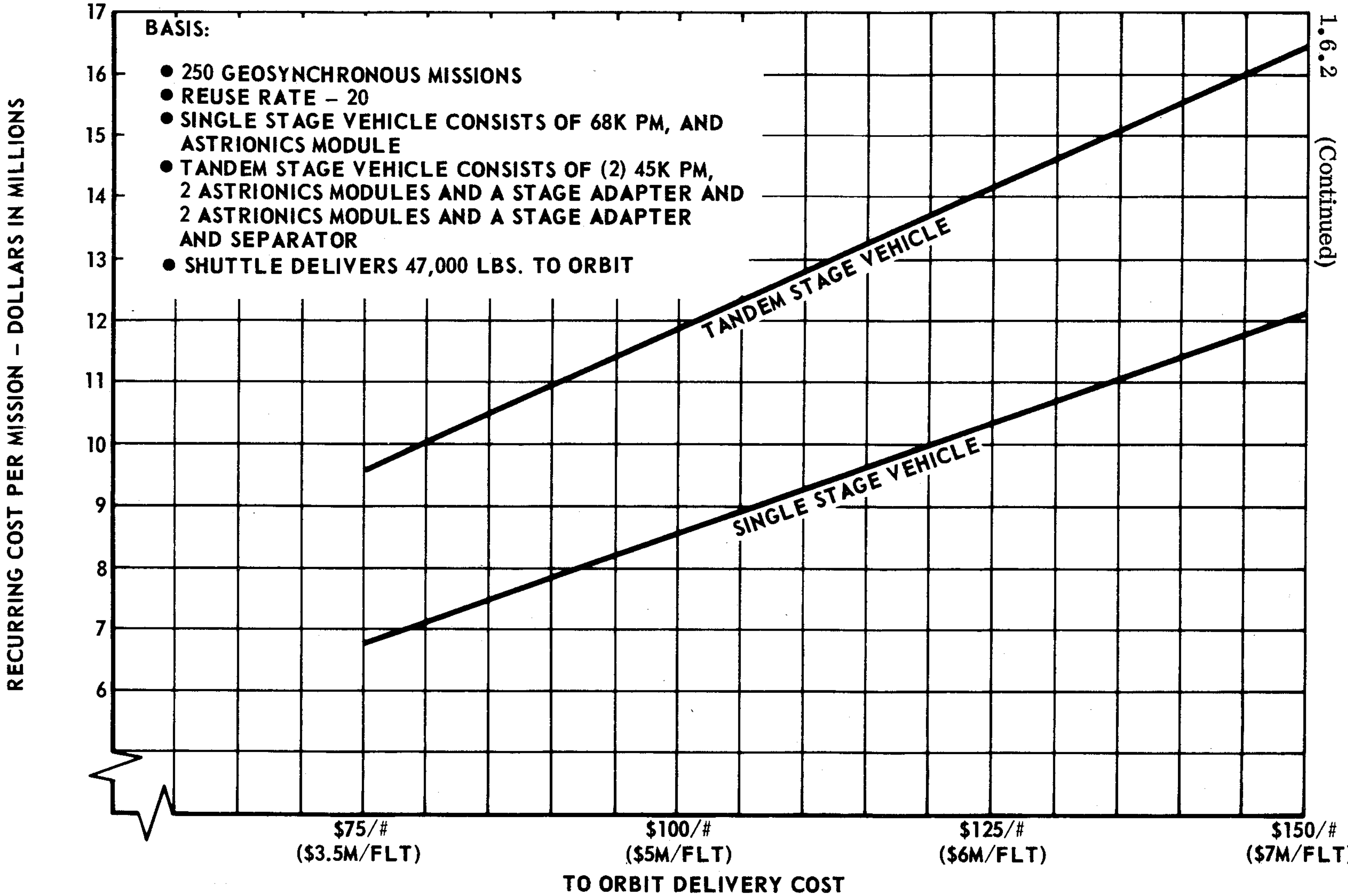


Figure 1.6.1.0-8. TOTAL PROGRAM COST SENSITIVITY AS A FUNCTION OF PROPELLANT TO ORBIT DELIVERY COST

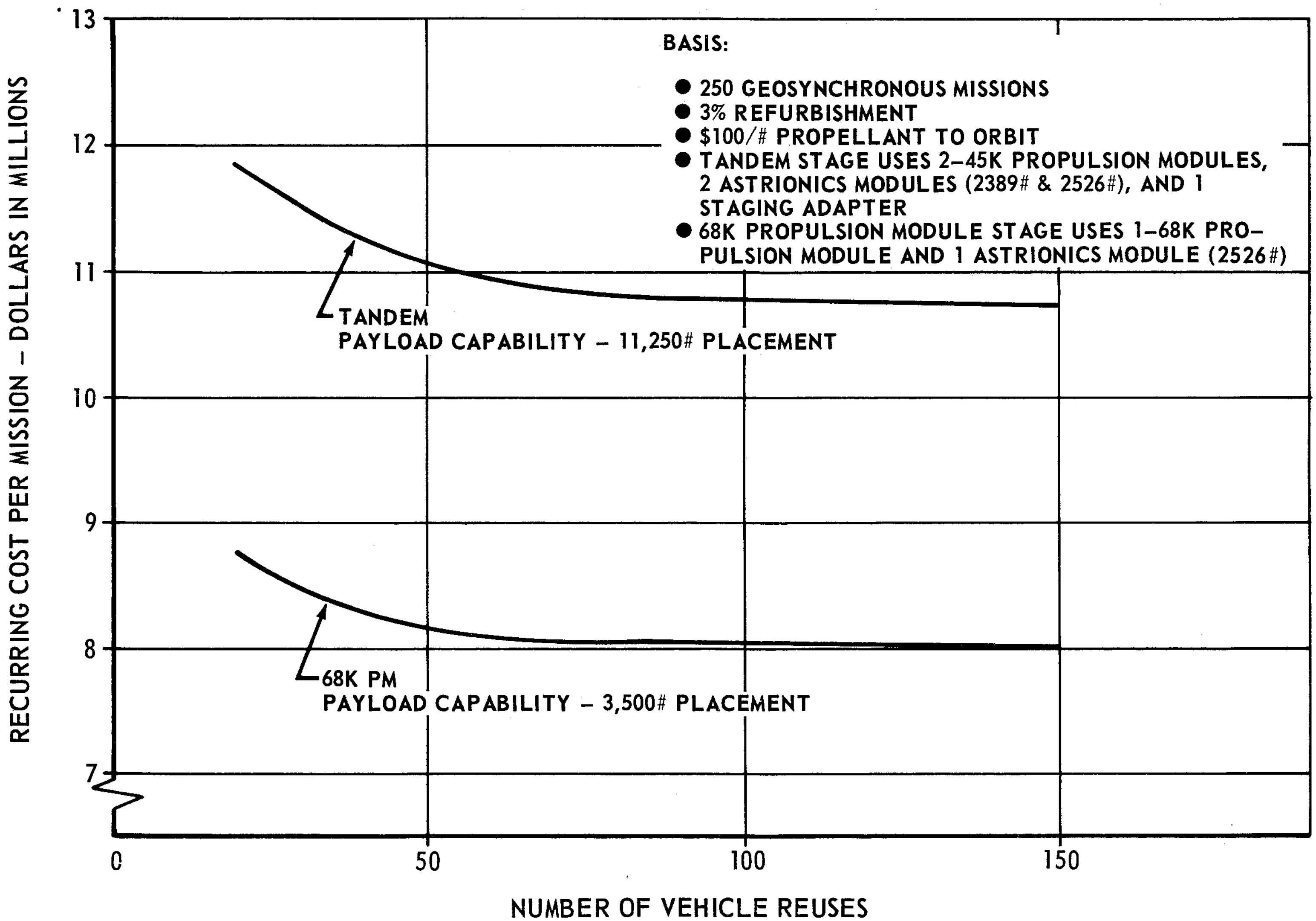


Figure 1.6.1.0-9. EFFECT OF VEHICLE REUSE ON SPACE TUG RECURRING COSTS

1.6.2 (Continued)

Figures 1.6.2.0-1, -2 and -3, the following conclusions were derived:

1. The non-recurring cost to develop a reusable stage with a 45,000 pound propulsion module plus astrionics module will be approximately 535 million dollars. (Includes \$45M for flight test hardware which can be used in the operational program.)

2. The additional non-recurring costs to provide manned capability (crew module plus manipulator arms) will be approximately 380 million dollars. (Includes \$70M for flight test hardware which can be used in the operational program.)

3. Provision of cargo containers, power kits, staging adapters, docking adapters, drop tanks, landing legs, RCS boosters, radar kits, clustering adapters, plug-in astrionics and environmental protection kits will increase the non-recurring cost by approximately 335 million dollars.

4. The non-recurring cost to develop the secondary reusable 20,000 pound propulsion module plus astrionics module will be approximately 414 million dollars (including \$44M for flight test hardware which can be used in the operational program).

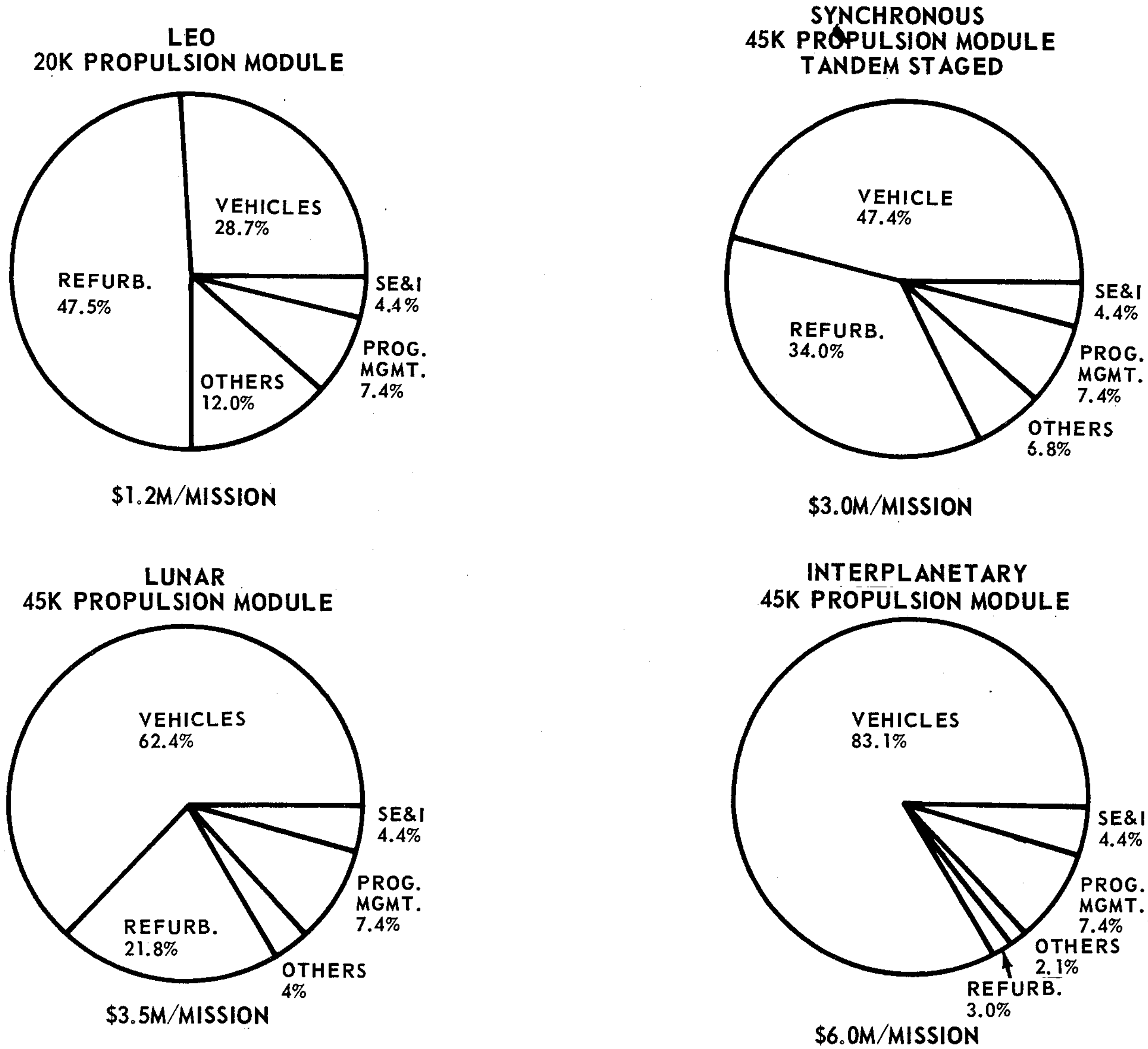
5. Total non-recurring costs will be 1.66 billion dollars for a complete Space Tug element inventory. (Includes \$161M for flight test hardware.)

6. The first unit cost of the unmanned Space Tug (45,000 pound propulsion module/astrionics module) will be approximately 15.7 million dollars.

7. The additional first unit cost for the crew module plus manipulator arms will be approximately 30 million dollars.

8. The first unit cost of the unmanned Space Tug (20,000 pound propulsion/astrionics module) will be approximately 14.9 million dollars.

9. The investment cost for any traffic model is highly dependent on the number of reuses, thus for LEO missions, with a reuse of 50 for the PM/AM, the investment cost is 28.7 percent of the recurring cost (less propellant costs). For synchronous missions, with a reuse of 20 for the PM/AM, the investment cost is 48 percent of the recurring cost (less propellant costs), as shown in Figure 1.6.2.0-1.



NOTES:

- OTHERS INCLUDES
  - LAUNCH OF TUG
  - RECOVERY OF TUG
  - ENGINEERING SUPPORT
  - PROGRAM INTEGRATION
  - REFURB. FACILITY MAIN.
  - SPARES
- 50 MISSION BASIS
- REUSE RATES
  - LEO – 50
  - SYN – 20
  - LUN – 10
  - INT – NONE

Figure 1.6.2.0-1. COST DISTRIBUTION - MISSION RECURRING COSTS EXCLUSIVE OF PROPELLANT DELIVERY COST

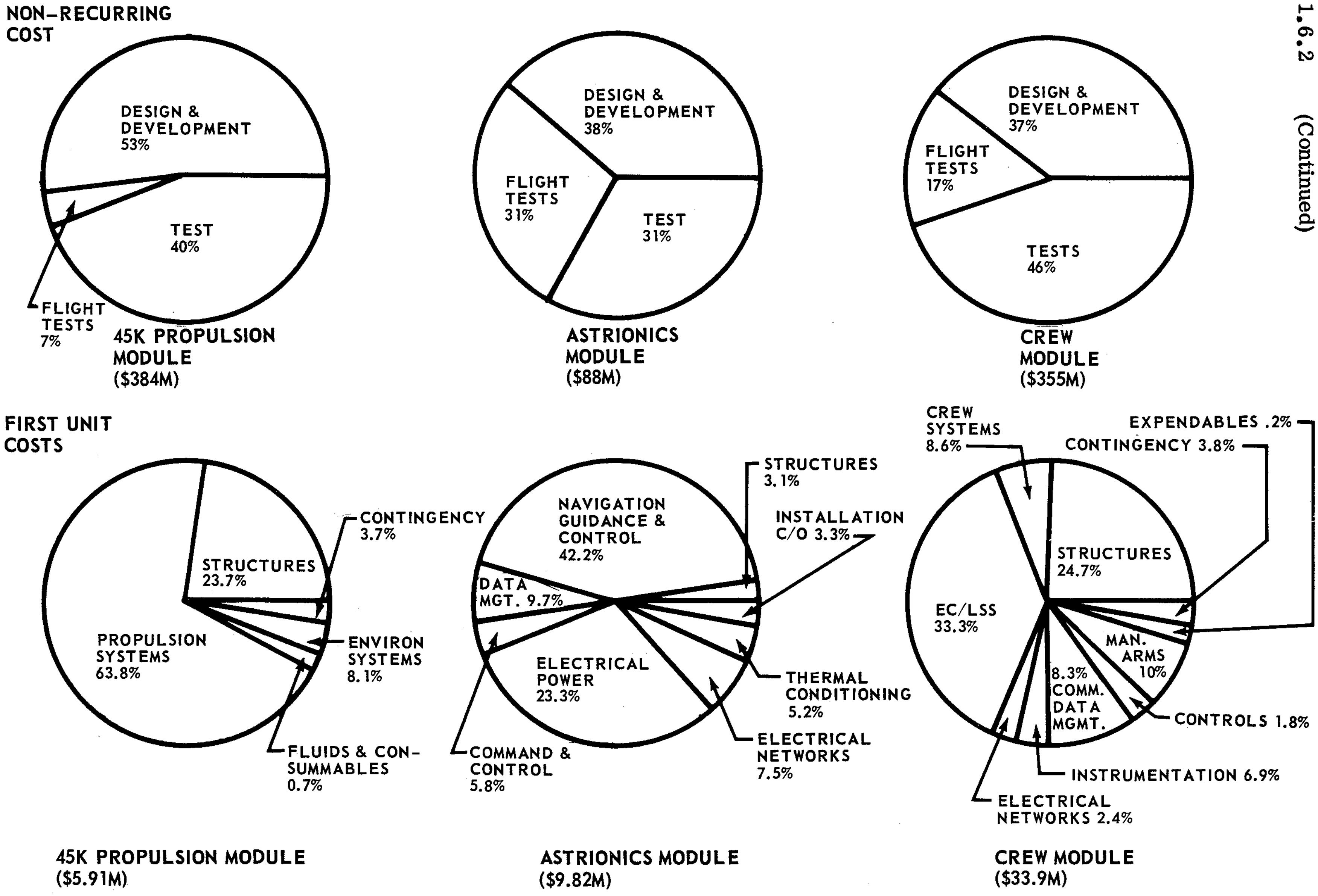
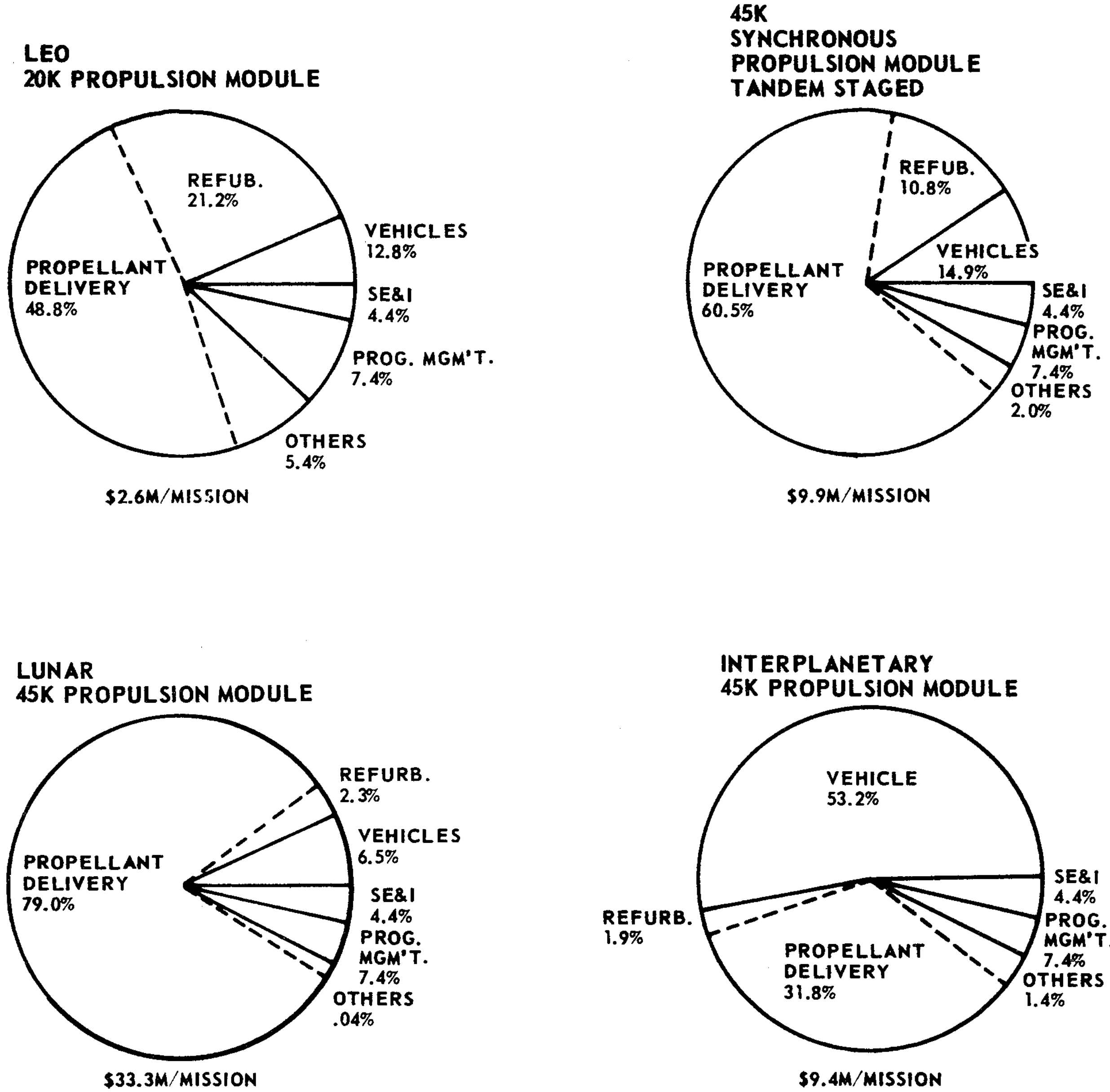


Figure 1.6.2.0-2. COST DISTRIBUTION - NON-RECURRING AND FIRST UNIT COSTS



NOTES:

- OTHERS INCLUDES
  - LAUNCH OF TUG
  - RECOVERY OF TUG
  - ENGINEERING SUPPORT
  - PROGRAM INTEGRATION
  - REFURB. FACILITY MAIN.
  - SPARES
- 50 MISSION BASIS
- REUSE RATES
  - LEO – 50
  - SYN – 20
  - LUN – 10
  - INT – NONE
- PROPELLANT DELIVERY
  - $75/# – LEO
  - $660/# – LUNAR

Figure 1.6.2.0-3. COST DISTRIBUTION – MISSION RECURRING COSTS WITH PROPELLANT COST INCLUDED

1.6.2 (Continued)

10. The operational costs are driven by the refurbishment costs and by the propellant delivery costs. These costs are between 70 and 80 percent of the operational costs. (See Figure 1.6.2.0-3).

11. Test costs (including flight tests) represent more than 50% of the non-recurring costs for complex modules (see Figure 1.6.2.0-2).

12. Cost drivers for the key Space Tug modules are: (see Figure 1.6.2.0-2)

    Propulsion module - Propulsion/Mechanical Systems - 64% First unit cost
    Astrionics module - Navigation, Guidance and Control - 42% First unit cost
    Crew module - Environmental Control/Life Support Systems - 33% First unit cost

13. Reuse of Space Tug components for more than 50 missions does not reduce mission recurring costs significantly.

14. For unmanned missions, the recurring costs (exclusive of costs for propellant delivery are:

    Low Earth Orbit - $1.15M per flight (20K PM plus AM, CM, and DA)
    Synchronous - $3.11M per flight (two 45K PM/AM stages plus CM and DA)
    Lunar - $3.47M per flight (45K PM with kits plus AM)

15. For manned missions, the recurring costs (exclusive of costs for propellant delivery are:

    Low Earth Orbit - $2.54M per flight (20K PM plus AM, MA, CM, and CaM)
    Lunar - $8.14M per flight (45K PM with kits plus AM, CM and Doughnut CaM)

16. For interplanetary missions with a single 45K expendable PM/AM stage, the recurring costs (exclusive of costs for propellant delivery) are $6M per flight.

This study (to the depth conducted) defined no difference in costs for design and operations in a ground based mode versus design for and operations in a space based mode. Obviously, some increased costs must be attributed to the space based mode to account for design complexity, in-space maintenance, increased inventories; fuel transfer losses, etc.

1.6.2 (Continued)

The above conclusions as well as all of the cost study results are based primarily on considerations for the Space Tug economics only. To fully evaluate the cost of the Tug future activities should consider the following pertinent areas which were not investigated as a part of this pre-Phase A study activity:

1. Variations in EOS weight and volume constraints. The space shuttle size at the present time is not fixed and will have a significant impact on the desirable space tug size and costs.

2. Space based vs. ground based operational modes. The design complexity of a space based space tug will be significantly greater than that of a ground based space tug to provide for the long period of time in space and in-space refurbishment. Building and operating this more sophisticated design will be more expensive.

3. Mission model variations. The mission model used for this study was based on a combined NASA/DOD program covering a ten-year period. The economical EOS/Space Tug size and operational modes will vary significantly as the mission model is changed.

4. Alternative configurations versus configuration size options. The impact of using a smaller size vehicle vs. an offloaded larger vehicle or the impact of using tandem smaller stage vehicles vs. a single large vehicle has not been fully investigated relative to a mission model and an integrated space program.

5. Payload retrieval. This study investigated only the costs of the Space Tug. No investigation was conducted to determine whether the payloads could be retrieved and recycled for reuse. Potential advantages of payload savings should be investigated.

6. Impact of Space Tug phase-in into the overall space program. Studies of incorporating the space tug into the Space Transportation System should investigate the impact of the phase-in timing, phase-in costs, budget constraints, etc.

1.7 NEW TECHNOLOGY IMPLICATIONS

The areas for technology development identified by this study are:

a. Gaseous LOX/LH_2 reaction control system.

b. On-board test and checkout system.

1.7 (Continued)

c. Vehicle design for the space based operations considering:

1. Reliability
2. Redundancy
3. Maintenance
4. Refurbishment

d. Manipulator arms systems

Since other elements of the integrated space program, i.e., space station, space shuttle and nuclear shuttle, are faced with similar technology requirements, it may be possible for the Space Tug to draw on the technology developments for these other space systems. Impact upon Tug costs and schedules would thereby be alleviated.

1.7.1 Reaction Control System Development

Use of gaseous-oxygen/gaseous-hydrogen for auxiliary propulsion is being extensively examined under the Earth-to-Orbit Shuttle program. Several technology development programs are currently funded. Among these studies are:

a. Ignition

b. Propellant injection and conditioning

c. Propellant feed systems

d. Thruster requirements, sizing and performance

These and follow-on EOS programs should fulfill the technology development requirements. However, since the Space Tug reaction control system demands will be relatively small compared to those of the EOS, a program of correlation of EOS system technology to Tug system size will be necessary.

1.7.2 On-Board Test and Checkout Systems

There are two generally accepted methods of providing an on-board checkout capability, both of which will require extensive analysis study. These are (1) a central computer for test control and data analysis, and (2) built-in test equipment (BITE) in each subsystem. The relative merits of these methods should be evaluated and a system combining the best of both modes defined.

1.7.2 (Continued)

The test and software requirements must be defined in depth before system design and development can be implemented. The EOS program which will precede the Tug development should provide most of the requirements and the technology for meeting these requirements.

1.7.3 Reliability, Redundancy, Maintenance and Refurbishment

Significant effort will be required to establish the Tug system design requirements relative to its reliability goals, the design redundancy to meet these goals, and the maintenance, refurbishment, and spares requirements to enhance the reliability and minimize the operational complexity these requirements should be evaluated considering both space based operations and ground based operations. The impact upon the system design of these different operational modes should be more fully understood.

In addition, the relationship of the various missions to reliability goals considering manned and unmanned missions and expendable and reusable modes should be defined and associated system impact determine.

1.7.4 Manipulator Arms and Associated Teleoperations

For the Tug to fulfill its role, manipulator arm systems with associated teleoperations are required. These systems would be used for both manned and unmanned missions for:

a. Tug self-assembly

b. Satellite placement and retrieval

c. On-orbit repair and maintenance

d. Space-Station assembly and support

e. Docking and rendezvous

f. Nuclear shuttle support and reactor change-out.

Control of these systems may be remote from man within the spacecraft or from ground stations. Autonomous operations without man in the loop will also be required.

No apparent technological breakthroughs are required to develop highly dexterious and versatile teleoperator systems. A critical need does, however, exist for research and technology in several subsystem areas as

1.7.4 (Continued)

defined in the Teleoperator/Robot Development Task Team Summary Report, October 13, 1970, (NASA Hq.), i.e.:

a. Manipulators

1. Subsystems requiring the greatest research and advanced technology effort include actuators, sensors and locomotion subsystems.

2. Further development of actuator subsystems is required to provide reduced weight and volume components, increased dexterity and versatile/special application tool design.

3. Research and technology needs in the sensor area include pressure and tactile sensors and multisensor integration.

b. Display, Control and Communication

1. Display technology advancement efforts should concentrate on TV components and systems, image enhancement, data format and rates and man-machine interface.

2. Specific display requirements for future teleoperator missions will include 3D video, predictive displays, flat screen displays, short-distance ranging displays, tactile displays and integrated displays.

3. Control research and technology development emphasis must be given to adaptive-supervisory control, handling qualities, vehicle navigation and guidance, and control logic.

4. In the development of control systems, significant effort must be directed towards the tradeoffs of manual vs. automated/adaptive control and remote vs. on-board control.

5. The existing state-of-the-art in communications technology should satisfy many requirements in the near term. Advances are required in solid state components, low-power high-efficiency transmitters and receivers, high-gain antennas and channel capacity.

1.8 CONCLUSIONS

This Pre-Phase A study of the feasibility of a Space Tug as one element of the planned integrated space program has met all of its objectives. All operational and environmental requirements have been examined. Systems

1.8 (Continued)

and subsystems options which may satisfy the requirements for each mission were identified and from these options appropriate systems and subsystems were selected. The differences in the systems as related to the different mission requirements were identified. Various modular concepts were investigated to provide system flexibility and commonality for all missions. Baseline configurations were selected and defined, and the capability of the configurations as related to the various missions were determined.

The conclusions reached in the study are, due to the nature of a Pre-Phase A study, preliminary but should provide the framework and direction for space program planning and subsequent study activity. Many are subject to re-evaluation as the integrated space program becomes clarified and as the design and inter-relations of the various interfacing hardware elements become better defined. Also, many of the conclusions are dependent upon the order of mission priority, payload requirements, and EOS capability.

1.8.1 General Conclusions

General conclusions reached in the study are:

a. A Space Tug, or other space propulsion stage is required to supplement the Earth-to-Orbit shuttle for accomplishment of the majority of the unmanned mission spectrum. The EOS is capable of delivering only 25% of the projected 763 missions in the representative mission model. An additional stage is required for the remaining 75%.

b. A Space Tug type system is a mandatory link in the planned integrated space program between the EOS, Space Station/Space Base, Nuclear Shuttle, Lunar Orbiting Station and Lunar Landing Exploration.

c. A reusable Tug offers major advantages to the integrated space program by (1) reducing recurring transportation costs by its own reusable nature, and (2) recovery and reuse of payloads. Round trip capability as provided by reusability is imperative for manned missions. Further reusability provides the capability for return of payloads and the physical access to reconnaissance and experimental data.

d. The modular Space Tug concept is advantageous to the overall space program as it will (1) permit the evolutionary development of the Tug's modules and kits and thus minimize design modification impact, (2) reduce the impact of the Tug on the space program peak funding levels, (3) increase the versatility of the Tug by allowing more vehicle configurations to be built from the modules and kits,

1.8.1 (Continued)

and (4) simplify the maintenance operations and reduce maintenance costs.

e. Mission modes should be employed wherein the same EOS (or EOS's) which places the mission components in earth orbit can remain on orbit to retrieve and return these mission components to earth after mission completion. If this cannot be accomplished the economic advantages of reusable systems may be negated by the cost of the additional EOS launches required for retrieval.

f. Within the mission and interface guidelines followed in this study, the overall manned and unmanned mission spectrum can be accomplished by an EOS with a 54,000 pound capability to the 100 n.m. 28.5° inclination orbit plus the Space Tug module and kit inventory identified by this study.

g. Interfaces with other hardware elements in the integrated space program have not been defined sufficiently to fix designs. This is particularly true of the EOS payload capability. The EOS payload capability for this study of 54,000 pounds to 100 n.m. 28.5° inclination orbit is subject to change. Other capabilities would require reexamination of the Tug component sizes and Tug operational modes. However, in recognition of this possibility, considerable parametric data were developed from which Tug systems and modes can be defined to be compatible with any EOS capability.

h. High energy missions, such as the synchronous missions, demand either a large stage, which is technically undesirable, or multiple smaller stages. Through the application of an "aerobraking" return mode the potential exists to increase the performance of a single stage and to reduce the single stage performance sensitivity and development risk.

i. A Tug which is space based will be dependent upon a propellant delivery logistics system. This could be either by direct refueling of the Tug by the EOS or by establishment and utilization of an Orbiting Propellant Depot. The method and costs of propellant logistics is the key issue in the integrated space program and must be studied before the relative advantages and disadvantages of space based and ground based modes can be fully defined.

1.8.2 Mission Peculiar Conclusions

Unmanned Earth Orbit Missions

An examination of the reusable Tug performing unmanned missions showed that:

a. Other than for synchronous missions, all missions can be satisfied by a single reusable 45,000 lb. propulsion module. For the synchronous missions with payloads less than the 10,000 lbs. requirement, tandem staged 45,000 lb. propulsion modules meet all requirements.

b. For 10,000 lb. synchronous payloads, the requirements are (1) tandem dual staged 45,000 lb. propulsion modules for placement, (2) for retrieval - dual staged clusters with two 45,000 lb. propulsion modules per cluster, and (3) for round trip - tandem dual staged clusters with three 45,000 lb. propulsion modules per cluster.

c. Equal sized reusable stages are preferable to optimized reusable stages for dual staged configurations since (1) commonality provides economy, and (2) the loss of payload capability with equal stages as compared to optimized stages is only 4%.

d. For equatorial geosynchronous earth orbit missions a departure orbit with an inclination of 28^{o} or less is desirable. Missions to synchronous orbit from a 55^{o} inclination require an additional one way velocity 1,940 feet per second.

e. A single reusable propulsion module should not be used in the conventional flight mode for the geosynchronous orbit mission because of high development risk (I_{sp}, λ' , etc., sensitivity). However, the aerobraking return mode has the potential of reducing this sensitivity and perhaps premitting a single stage to be used. Use of this mode will also enhance multi-staged Tug capability.

f. A secondary propulsion module can satisfy all the polar missions which cannot be performed by the EOS alone. However, an offloaded primary propulsion module can also accomplish these missions. Unless another requirement exists for the secondary propulsion module, it appears for economy of inventory, that only the larger primary module should be considered for unmanned missions.

1.8.3 Manned and Unmanned Support Missions in Low Earth Orbit

The investigation of missions to support a Space Station by rotating crew and cargo, and to support refueling in space showed that:

a. The need for a Tug propulsion module to support a Space Station is dependent upon the EOS capability and the actual cargo requirements. The trend of the Space Station program toward small modules and limited cargo requirements can result in the EOS being capable of performing this mission direct. The crew and cargo modules as defined by this study can, however, be used to transport crew, passengers and cargo in conjunction with the EOS, with or without Tug propulsion module.

b. Utilization of a Tug propulsion module with the EOS in a ground based mode offers a 30% to 50% improvement in the delivered cargo by the EOS alone.

c. Utilization of a space based Tug can provide 90 to 145% larger gross payloads to orbit than can direct delivery with the EOS. Discounting the on-orbit Tug fuel required, reduces the payload advantage of the space base Tug/EOS combination to an order of 50% greater than that of an EOS alone.

d. While both ground and space based Tugs will deliver a net payload greater than that of the EOS alone, the capability decreases with mission time.

e. For short duration time missions, space based Tug/EOS net payload capability will be slightly greater than that of the ground based Tug/EOS.

f. For on orbit mission times of seven (7) days, the net payload capability of the EOS alone is approximately equivalent to both the space based or ground based EOS/Tug combination.

g. Secondary propulsion module sizes are indicated for these support missions. An off-loaded primary propulsion module can, however, accomplish these missions with only a minor increase in the fuel required for a given mission.

1.8.4 Lunar Landing Missions

The lunar landing missions studied included manned and unmanned coplanar landings and manned and out-of-plane abort and rescue missions. It was found:

1.8.4 (Continued)

a. For the nominal manned and unmanned coplanar landing conditions the baseline 45,000 lb. propulsion module meets the mission requirements.

b. Unlimited rescue capability, i.e., rescue of personnel from any point on the lunar surface at any time, requires a large multi-staged Tug. A "rescue and wait" rescue mode will substantially reduce the vehicle size and complexity.

c. An uprated single RL-10-3-8 can satisfy the lunar landing payload requirements. Its relative low thrust will, however, result in a performance degradation from optimum of up to 7% for the largest unmanned cargo mission.

1.8.5 Saturn V/Space Tug Fourth Stage

Investigations of the Space Tug propulsion module as a fourth stage on Saturn V for translunar and planetary injection missions showed:

a. Payload capability is relative insensitive to propulsion module size.

b. A 45,000 lb. stage sized for other missions is adequate for translunar and interplanetary missions.

c. The payload capability is not increased by the addition of more than one Tug stage.

d. Saturn V upper stage missions impose design loads but do not impose size constraints on the Tug.

e. Space Tug weight and envelope will require Saturn V structural modifications or restricted launch availability to conform to lower design winds.

1.8.6 Interplanetary Missions Launched from Earth Orbit

Tug interplanetary missions out of earth orbit were not used to size the Space Tug. Use of the baseline 45,000 lb. propulsion module in an expendable mode will provide reasonable interplanetary payloads. Use of two equal tandem expendable propulsion modules will increase the payload capability substantially.

1.9 RECOMMENDATIONS

Four major areas should be investigated prior to further configuration design studies of the Space Tug System. These are:

a. Economics of EOS/Space Tug Operations.

b. Interface requirements.

c. Orbital propellant logistics.

d. Potential of aerobraking return mode for high energy missions.

Economic analyses of EOS/Space Tug operations should define:

a. Operational modes and system sizes that provide the best economy.

b. The required inventory of transportation systems.

c. Whether this inventory should include current expendable upper stage systems.

d. The operations and cost implications of clustered payloads.

e. The cost savings potential of payload retrieval and reuse.

f. The effects of budgetary constraints on system implementation and operation.

EOS/Tug interface requirements are currently imposed on Tug systems. Interface requirements analyses of this interface and other Space Transportation System interfaces are required to resolve mutual problems.

Orbital propellant logistics are a key issue in the integrated space plan. Studies are required to:

a. Determine quantitatively the need for orbital fueling.

b. Determine whether this need can be met economically.

c. Determine orbital fueling requirements impact on Shuttle and Tug systems.

Future studies should evaluate the potential of the aerobraking return mode for high energy missions to:

1.9 (Continued)

a. Determine representative inert weight penalties associated with aerobraking (i.e., thermal protection and aerodynamic surfaces).

b. Determine associated impact on astrionics (e.g., impact of power, accuracy and reliability, requirements).

c. Compare gross required Space Tug weights for equal payloads for conventional and aerobraking modes of operation.

d. Define sensitivities of Tug weights to various re-entry environments.

e. Define sensitivity of re-entry environments to trajectory anomalies.

No further Space Tug configuration design studies should be performed until the results of the above recommended studies are available.